TYPES OF BOILERS

American School
Chicago, U. S. A.

TYPES OF BOILERS

Prepared especially for the instruction and training of students of the American School

By

ROBERT H. KUSS, M.E.
Consulting Mechanical Engineer
American Society Mechanical Engineers
International Railway Fuel Association

NORMAN E. BURKHARDT
RT. 3 - BOX 89
FRAZEYSBURG, OHIO 43822

American School
Chicago, U. S. A.

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INTRODUCTION

Function of a Simple Boiler. A steam boiler is a closed metallic vessel in which steam is generated from water by the application of heat. Only that part of a complete contrivance used for generating steam from water which is employed in the absorption of heat is known as the boiler. All of that portion of the arrangement in which the fuel releases its heat by fire is known as the furnace. Hence, the functions of the furnace and the boiler are exactly opposite; the former generating or liberating heat, and the latter absorbing a part of the heat delivered to it by the furnace.

The purpose of a steam-generating equipment is to convert the available energy of fuel into heat energy carried by steam, so that it may be employed elsewhere, either in an engine in the creation of mechanical energy or used, without conversion, as heat. Where the heat energy of the steam is to be converted into mechanical energy it is necessary to generate the steam at a greater pressure than that of the atmosphere. It follows that the boiler must be made amply strong to withstand the pressure intended, and must also be protected against the consequences of careless, unskillful, and dangerous operating methods.

Boiler Accessories. To operate a boiler safely and economically there must be certain fittings and accessories, some of which are used in the care of the boiler, while others serve to increase its economy. Among the most important attachments and appurtenances are the following:

Feed Pump, or Injector. A feed pump, or injector, with valves, piping, etc., supplies water to the boiler.

Gage Cocks and Water Gage. Gage cocks and glass water gage show the attendant the height of water, or the water level, as it is called, in the boiler.

Pressure Gage. A pressure gage indicates the pressure of steam in the boiler. The pressure is usually measured in pounds per square inch.

Safety Valve. A safety valve allows steam to escape from the boiler when the pressure exceeds a certain fixed amount. This attachment, being a safety device, should be automatic and reliable.

Blow-Off Pipe. A blow-off pipe, with its valves, is used to blow out sediment from the boiler, reduce the amount of water in the boiler, or empty it.

Steam Pipe. A steam pipe, with its valves, conducts the steam from the boiler to the place where it is to be used.

Manholes and Handholes. Manholes and handholes, with covers, are used for making examinations, and when repairing or cleaning.

*Fusible Plugs.** Fusible plugs are designed to give warning when the water level becomes too low.

*High- and Low-Water Alarms.** High- and low-water alarms give warning when the water level is too high or too low.

*Heaters.** A heater is a device for raising the temperature of the feed water to a point as nearly equal as possible to that of the water in the boiler.

Columns, Lugs, or Brackets. Columns, lugs, or brackets are supports for the boiler.

Masonry. Masonry is used for enclosing the boiler and keeping it in position, and in many cases for keeping the hot gases in contact with the heating surface.

Furnace Fittings. Furnace fittings include grate bars, bearer bars, fire doors, ash-pit doors, dead-plates, door-liners, etc.

Damper Frame and Damper. The damper frame and damper are used to control the draft by varying the size of the opening through which the gases are allowed to escape from the boiler setting.

Breeching. The breeching carries the gases from the boiler or its setting to the chimney.

Chimneys. The chimney carries away the waste gases and creates draft.

Tools. Tools include shovels, slice bars, scrapers, tube brushes, soot blowers, gasket molds, etc.

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*Although desirable, they are not absolutely necessary, as a boiler can be successfully operated without them.

CLASSIFICATION

Basis of Classification. The almost endless variety of boilers now in use is due largely to the many conditions under which they are used. Another reason for the numerous forms is the resourcefulness of designing engineers, who, during the last century, have sought to produce, at moderate cost, steam generators which are at once safe, durable, and economical.

A proper grasp of the subject requires that an orderly classification of boilers be attempted. A number of different methods are employed for this purpose, but only those most commonly used are here given. Fortunately, many of the names applied to boilers are sufficiently descriptive, so that little difficulty will be found in locating a boiler in its particular field when once its proper name is known. Much valuable time may be saved, and a better understanding of the subject gained, by selecting one design of boiler to represent a given class. Again, a classification tends to bring out interesting and important features.

All boilers possess one or the other of the following pairs of characteristics:

Fire Tube and Water Tube
Vertical and Horizontal
Stationary and Non-Stationary or Portable
Externally Fired and Internally Fired

There are some designs which employ both characteristics of a pair; for instance, a boiler may have both fire tubes and water tubes; may not be distinctly either vertical or horizontal, but have a position midway between these two.

Boilers are also classified according to the pressure at which they operate, and are then known either as *high-pressure* or *low-pressure* boilers. The pressure at which a boiler is intended to operate determines only how strong the parts must be, and need not affect the selection of the scheme of putting the parts together. Consequently, low-pressure boilers and high-pressure boilers may be exactly alike in external appearance though their construction details and the materials of which they are made may be radically different. Besides, boilers designed to be used at high pressure are frequently used at low pressure. In view of the foregoing, a classification based on pressures alone would not be especially serviceable, even though to boiler manufacturers and engineers the expres-

sions "high-pressure" and "low-pressure" at once bring to mind characteristics of construction peculiar to each group.

Scheme of Classification. The scheme of classification according to *use* and *form* is given as follows:

- According to Use
  - Stationary
    - Early Forms
    - Plain Cylindrical
    - Single Flue, Externally-Fired
    - Flue Boilers
      - Cornish (Single-Flue)
      - Lancashire (Two-Flue)
      - Galloway
    - Multitubular
      - Externally-Fired
      - Internally-Fired (Return-Tubular)
    - Fire-Box Boilers
      - Horizontal
      - Vertical
    - Water-Tube Boilers
      - Straight-Tube
      - Curved-Tube
      - Horizontal
      - Vertical
      - Sectional
      - Non-Sectional
    - Mixed Types
    - Peculiar Forms
  - Locomotive
    - Multitubular Fire-Box (Common Form)
    - Wootten Type
    - Corrugated Furnace
    - Peculiar Forms
  - Marine
    - Early Forms (Box or Rectangular)
    - Scotch or Drum
    - Return-Tubular
    - Through-Tube
    - Water-Tube
      - Curved-Tube
      - Straight-Tube
      - Sectional
      - Non-Sectional
    - Launch Boilers
- According to Form
  - Early Forms
  - Flue
    - Cornish (Single-Flue)
    - Lancashire (Two-Flue)
    - Galloway
    - Single Flue (Externally-Fired)
  - Fire-Tube (Multitubular)
    - Horizontal (Common Form)
    - Vertical
    - Return-Tubular
    - Through-Tube
    - Fire-Box
    - Peculiar Forms
  - Water-Tube
    - Horizontal
      - Straight-Tube
        - Sectional
        - Non-Sectional
      - Curved-Tube
    - Vertical
      - Straight-Tube
      - Curved-Tube
    - Peculiar Forms
  - Mixed Types

Definitions. The following definitions should be remembered:

Fire-Tube Boiler. A fire-tube boiler is one having the heating surface composed largely of tubes which are surrounded by water, the hot gases passing through them.

Water-Tube Boiler. A water-tube boiler is also composed of tubes, but in this case the water flows through the tubes, while the hot gases pass around them.

Sectional Boiler. In a sectional boiler the tubes and corresponding headers form comparatively small units. Each unit is complete in itself; that is, it is in communication with a steam and water drum but is independent of the other units.

Non-Sectional Boiler. A non-sectional boiler is one having all the tubes in communication with one another; in other words, all or nearly all the tubes are expanded into a common header or drum. The boiler is not made up of units.

Single-Tube Boiler. A single-tube boiler is one which is made up of single tubes.

Double-Tube Boiler. A double-tube boiler has a small tube inside of the regular tube and concentric with it.

Externally-Fired Boiler. A boiler is externally fired when the furnace walls do not form a part of the boiler-heating surface but are built out of fire brick or other refractory material.

Internally-Fired Boiler. In the internally-fired boiler the furnace walls are a part of the boiler-heating surface as well as a part of the furnace; the Scotch marine is a good example.

Fire-Box Boiler. A fire-box boiler is one type of internally-fired boilers in which the furnace walls are flat or nearly so. The locomotive boiler is the best example.

EARLY FORMS OF BOILERS

The earliest boilers of which we have reliable record were spherical. They were of cast iron and set in brickwork. It was customary to set this type of boiler with the fire underneath and construct flues in the brickwork to conduct the hot gases around the boiler just below the water level. The hot gases passed entirely around the boiler before escaping to the chimney.

Haystack Boiler. The next form to be generally used was that invented by Newcomen in 1711. On account of its peculiar shape

it was called the "Haystack" or "Balloon" boiler. It was of wrought iron and had a hemispherical top and arched bottom. The fire was placed underneath the arched portion, the hot gases surrounding the lower part of the boiler. An improved form of the Haystack boiler is shown in Fig. 1. Smeaton placed the fire inside the shell and arranged internal flues for conducting the hot gases to the chimney. This arrangement increased the heating surface and, consequently, the economy of the boiler.

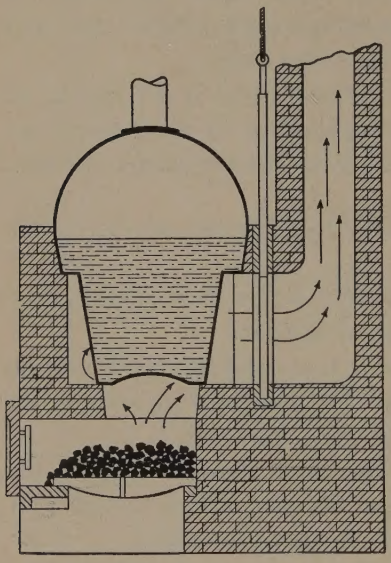


Fig. 1. The Haystack Boiler

Wagon Boiler. To increase the heating surface still more, James Watt introduced his "Wagon" boiler, Fig. 2. The top was semicylindrical and the sides curved inward. The curved plates assisted in the formation of side flues. The hot gases passed from the grate beneath the boiler to the rear, through the left-hand flue to the front, then through the right-hand flue to the rear, and thence to the chimney. This was called the "wheel draft" because the gases passed entirely around the boiler. In the large sizes a flue was placed in the boiler. The products of combustion returned through this flue to the front after passing under the boiler to the rear, as in the small sizes. On issuing from the flue at the front, the gases divided and passed to the chimney at the rear by means of the flues in the brickwork. This form of draft was called the "split draft".

Watt used a column of water in the vertical feed pipe as a pressure gage; the rise and fall of this column also controlled the damper. The feed was regulated by a float.

Although such boilers as the Haystack, Wagon, and others were fairly satisfactory at the time they were invented, they could not withstand the higher pressures which soon became common.

About the beginning of the nineteenth century the cylindrical boiler was introduced. The earliest forms were the plain cylindrical boiler and the "egg-end" boiler. The difference was in the form of the ends—those of the former were flat and of cast iron, while the ends of the latter were hemispherical and made of wrought

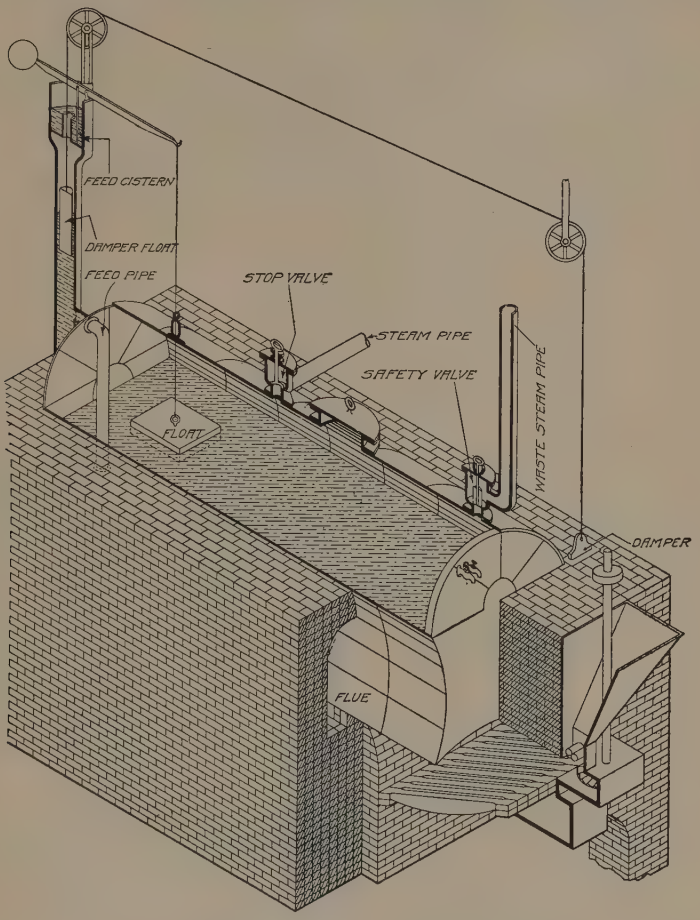


Fig 2. Diagrammatic Sketch of Watt's "Wagon" Boiler

iron. The egg-end boiler required no staying or bracing because its form is, with the exception of a sphere, the strongest to resist internal pressure.

Cylindrical Boilers. The cylindrical boiler consists of a shell of wrought-iron boiler plate and ends of the same material or of cast

iron. It is set in brickwork as shown in Fig. 3. The boiler is about two-thirds filled with water, the remaining third forming the steam space. To collect and store the steam as it rises from the water a steam dome is added. The steam pipe is attached to the dome, to which the safety valve is connected also. The hot gases from the fire pass under the boiler to the rear and then to the chimney.

The heating surface of this type is small for a given diameter unless the boiler is very long. As all sediment collects in the bottom where the heat is most intense, the plates are likely to be burned. Sediment and scale being poor conductors of heat, the heat remains in the plates and burns them instead of passing to the water.

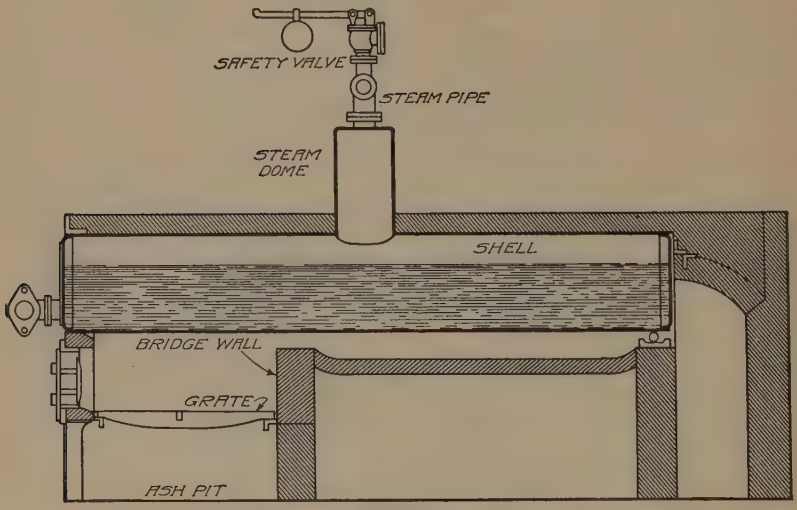


Fig. 3. Cylindrical Boiler and Setting

The disadvantages—the small heating surface and the collection of sediment—do not seem so serious when the simplicity, durability, and strength of construction, and the ease of cleaning and making repairs are considered.

The plain cylindrical boiler is adapted for mining districts and other places where fuel is abundant and where skilled boilermakers are not readily found. This boiler is made very long to obtain the required heating surface, the length sometimes exceeding fifty feet. Some of these boilers are still in use where relatively low operating pressures are allowed, but they are being rapidly displaced.

MODERN FLUE BOILERS

In order to get the necessary heating surface in the cylindrical boiler without making it excessively long, it was made with an internal flue through which the hot gases passed to the chimney. This flue was quite large and extended from end to end of the boiler. In the United States, Oliver Evans used this type as early as 1800. In England, it led to the internally-fired flue boilers which were, and are still, extensively used.

CORNISH BOILER

Horizontal—Single-Flue—Internally-Fired. When it was found that a large proportion of the total heat of combustion was lost by radiation and air infiltration, a Cornish engineer named Trevithick conceived the idea of placing the fire inside of a large internal flue. The type he introduced is known as the Cornish boiler.

Path of Hot Gases. The products of combustion pass from the fire on the grate bars *C*, Fig. 4, through

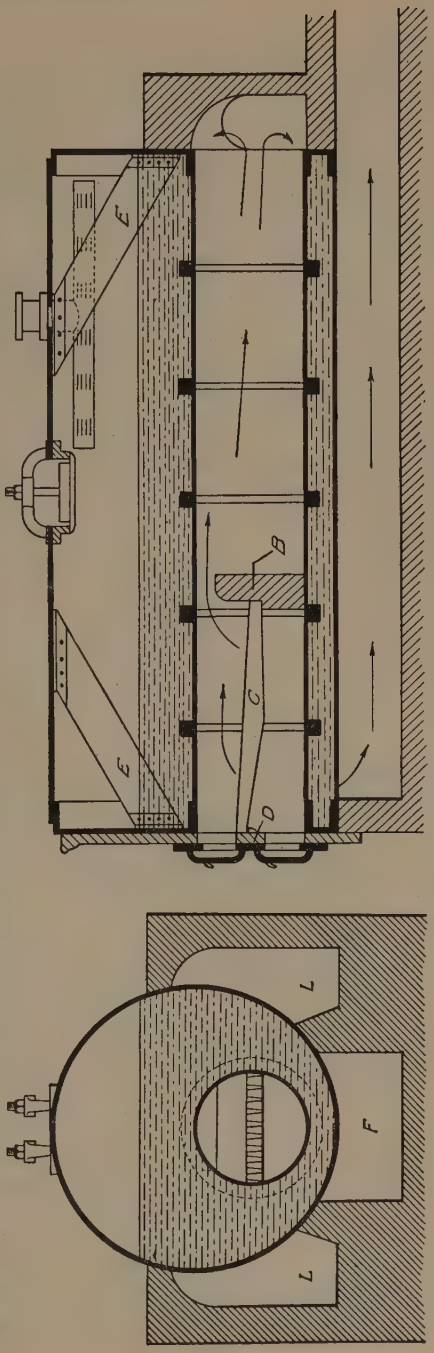


Fig. 4. Transverse and Longitudinal Section of Cornish Boiler

the flue to its back end, where they divide and return to the front end by means of the lateral flues L in the brickwork. At the front the hot gases pass downward and, uniting, pass through the flue F in contact with the bottom of the boiler. On leaving the boiler they go to the chimney. This arrangement of flues reduces the temperature of the gases before they come in contact with the bottom of the boiler, where sediment collects. The grate bars rest on the dead plate D at one end and on the bridge B at the other, Fig. 4. If made in two lengths, as is often the case, they are supported at the center by a cross bearer. The bridge is built of fire brick, and the external flues are lined with fire brick. The heads are stayed to the shell by gusset stays $E\,E$.

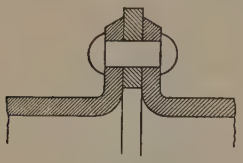


Fig. 5. Adamson Ring Furnace Construction

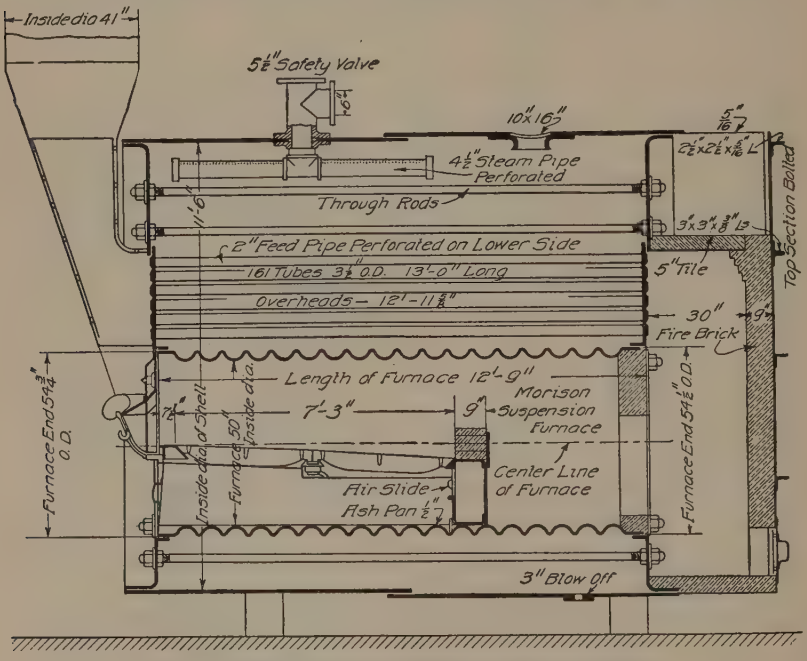


Fig. 6. Section of Morison Boiler Showing Corrugated Flue
Courtesy of Joseph T. Ryerson & Son, Chicago

Taking Care of Expansion. The large internal flue is the hottest part of the boiler because it contains the fire. For this reason the flue has greater linear expansion than the shell, and, when

the flue is a plain cylinder, the increase in length causes the ends to bulge. When the boiler is cold, the flue returns to its normal length. This lengthening and shortening will soon loosen the flue at the ends. To overcome this, the flue is sometimes made up of several short rings flanged at the ends and joined by being riveted to a plain ring. This construction is shown in section in Fig. 4. Another method is shown in section in Fig. 5. The plain rings are riveted to the curved rings; the latter take up the expansion, slightly increase the heating surface, and strengthen the flue against external pressure. This form is known as the "Adamson Ring". The same results may be obtained by the use of the corrugated flue, one form of which is shown in Fig. 6. The corrugated flue has many advantages over the devices shown in Figs. 4 and 5; it is frequently used in internally-fired boilers.

LANCASHIRE BOILER

Horizontal—Two-Flue—Internally-Fired. It can be proved, both by experiment and by calculation, that with a given thickness of material cylinders of large diameter cannot withstand as much pressure as smaller ones. For this reason, and on account of the short distance a fireman can throw coal accurately, the Cornish boiler is suitable for small powers only. If it is made too large, the flue is likely to collapse; but, on the other hand, if the diameter of the flue is too small, the grate will be insufficient in area. When this form of boiler is to be used in a large size, it is modified by using two flues instead of one. This is called the Lancashire boiler. It is like the Cornish except that it has two flues and, of course, two furnaces.

The flues are sometimes continued separately to the end. If they merge into one large flue, which forms the combustion chamber, it is called the "breeches-flued" or duplex furnace boiler. These furnaces are fired alternately; the unburned gases set free from the freshly-fired coal are burned on meeting the hot gases from the incandescent coal of the other furnace. This arrangement aids in preventing the escape of partly burned gases.

The main disadvantage in the design of the Lancashire boiler is the difficulty in finding room for the two flues without greatly increasing the diameter of the boiler. Also, the small furnace

space is unfavorable to the complete combustion of the gases, the space for mixing and burning being restricted. The combustion chamber of the breeches-flued boiler increases the space, but the construction at the junction of the two flues is weak and has been responsible for many explosions.

GALLOWAY BOILER

Horizontal — Two-Flue — Internally-Fired — Galloway Tubes. Another boiler of the same general form is the Galloway, shown in Figs. 7, 8, and 9. It was developed with a view to overcoming the

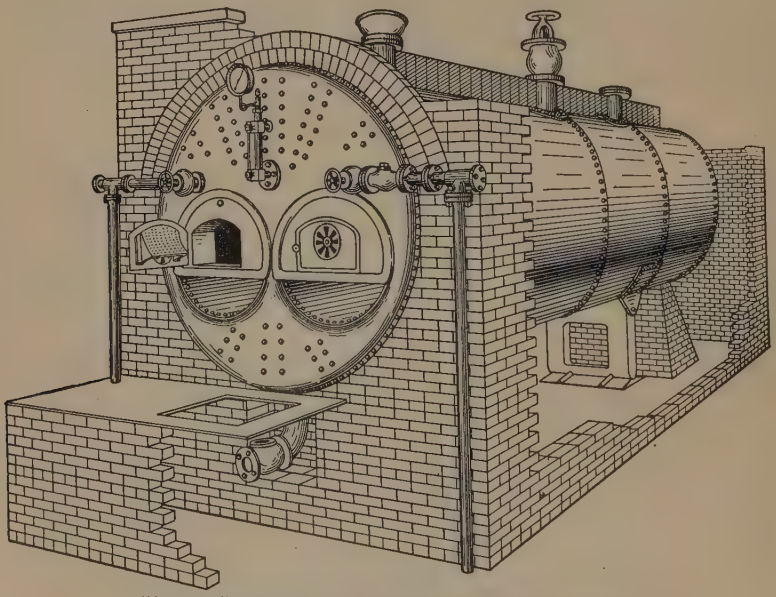


Fig. 7. Galloway Boiler. Brick Setting Partially Removed

shortcomings of the Lancashire boiler by providing obstructions in the flues to cause an intimate mixture of the gases of combustion, at the same time adding efficient heating surface; the cross flues also serve to create a circulation of water around the bottoms of the main flues, thus overcoming a serious objection to the Lancashire boiler, which is deficient in this respect.

Two Types. There are two different forms of Galloway boilers: those having two distinct flues, and those having two furnaces

which unite into one large flue. The earlier form has two flues extending the length of the boiler; behind the furnace short tubes, as shown in Fig. 8, cross the flues.

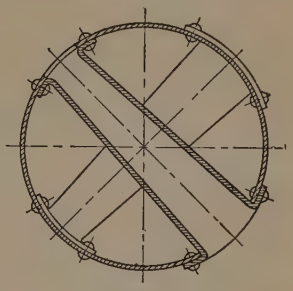


Fig. 8. Cross Flues in Two-Flue Galloway Boiler

In the later form, the two flues merge into one large flue of the shape shown in Fig. 9. This flue has corrugated sides and the conical tubes are staggered, thus insuring a thorough breaking up of the currents of hot gases. The tubes are made conical to facilitate removal for repairs. The shape of the tube also permits the water to expand on being heated, and the particles to rise vertically without disturbing the water on the heating surfaces above. The conical tubes are more generally riveted than welded because the removal of a tube that is welded leaves a large hole in the flue. This form of flue boiler marked a big advance over the earlier forms, partly due to the inherent improvements

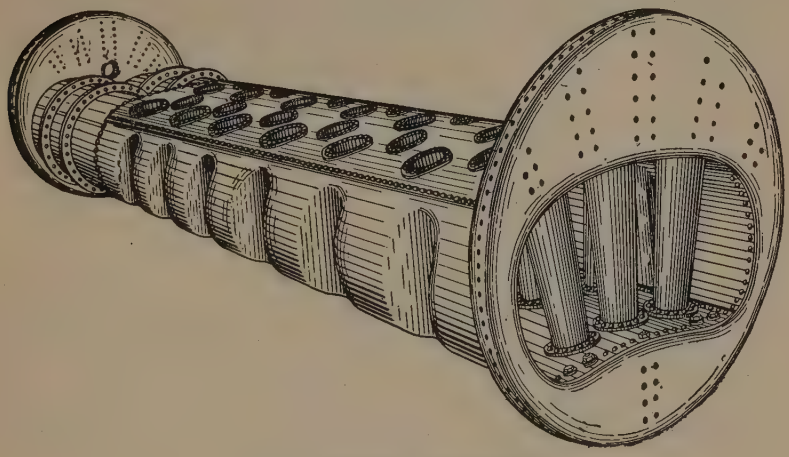


Fig. 9. Later Form of Galloway Flue

and partly because the manufacturers realized the importance of related features, such as skillful firing and providing adequate draft. Many of these boilers are still in use in America as well as in England.

FIRE-TUBE BOILERS

COMMON HORIZONTAL TYPE

Single-Flue Boiler. *Single Fire Tube—Externally-Fired.* In the Cornish, Lancashire, and Galloway boilers, the large internal flue served as a fire box. There was, however, a flue boiler having the fire external to the shell. The boiler shown in Fig. 10 resembles the plain cylindrical boiler, illustrated by Fig. 3, both in appearance and setting, but it has one or more large flues extending from end to end. This increases the heating surface to such an extent that the boiler can be considerably shorter than the plain cylindrical boiler. Note that the gases leave the setting on the front end.

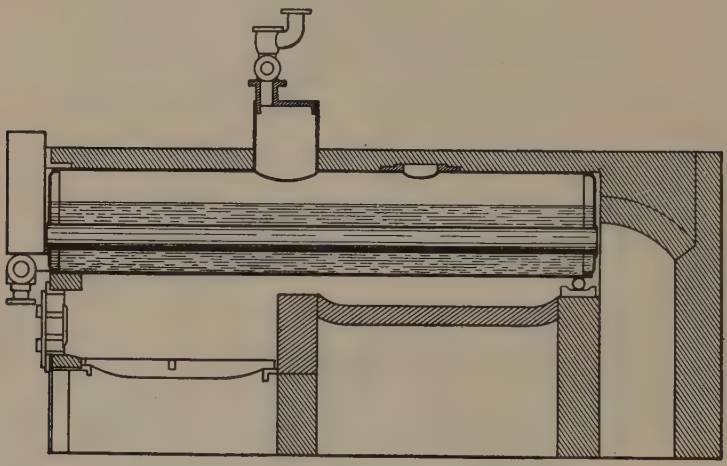


Fig. 10. Section of Cylindrical Flue Boiler

Multitubular Boiler. *Many Small Fire Tubes—Externally-Fired.* When engineers found that the internal flue was an advantage, they soon added more tubes. As the number increased, the size diminished until they became of the size used at present. This is a brief statement of the development of the multitubular boiler. For many years this type of boiler has been commonly used for stationary work, and, although other types possess advantages for certain conditions, it is still considered economical, reliable, easily handled, and safe, if constructed of good material and operated with care and intelligence, in small and medium-sized plants operated at moderate pressures.

Description. Figs. 11 to 14 are selected to illustrate this boiler. The boiler without the brick setting is shown in Fig. 11. It consists of a steel cylindrical shell and numerous small tubes extending from end to end. These tubes are 3 to 4 inches in diameter and are fastened to the two ends, called tube sheets, by expanding the tubes into the sheet and beading them over on the outside. The shell is made of steel plates $\frac{1}{4}$ to $\frac{3}{4}$ inch in thickness, depending on the diameter and pressure. At the front, the shell plates extend beyond the tube sheet and are cut away to allow the waste gases to enter the uptake. About one-third the volume of the boiler is occupied by the steam; the other two-thirds is filled with water and tubes. The water line is a short distance (from 3 to 8 inches) above the top row of tubes.

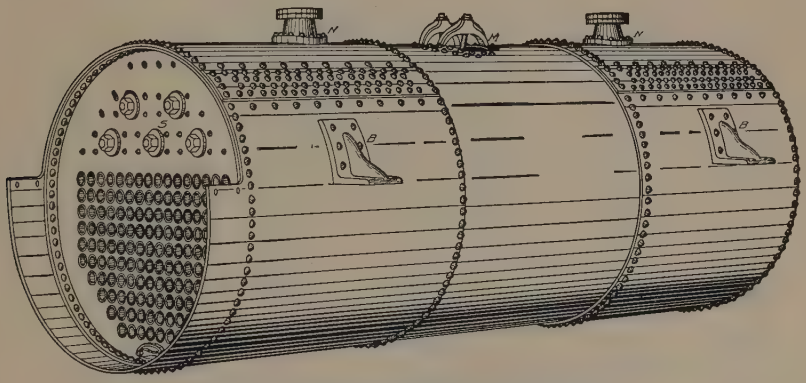


Fig. 11. Multitubular Boiler without Its Setting

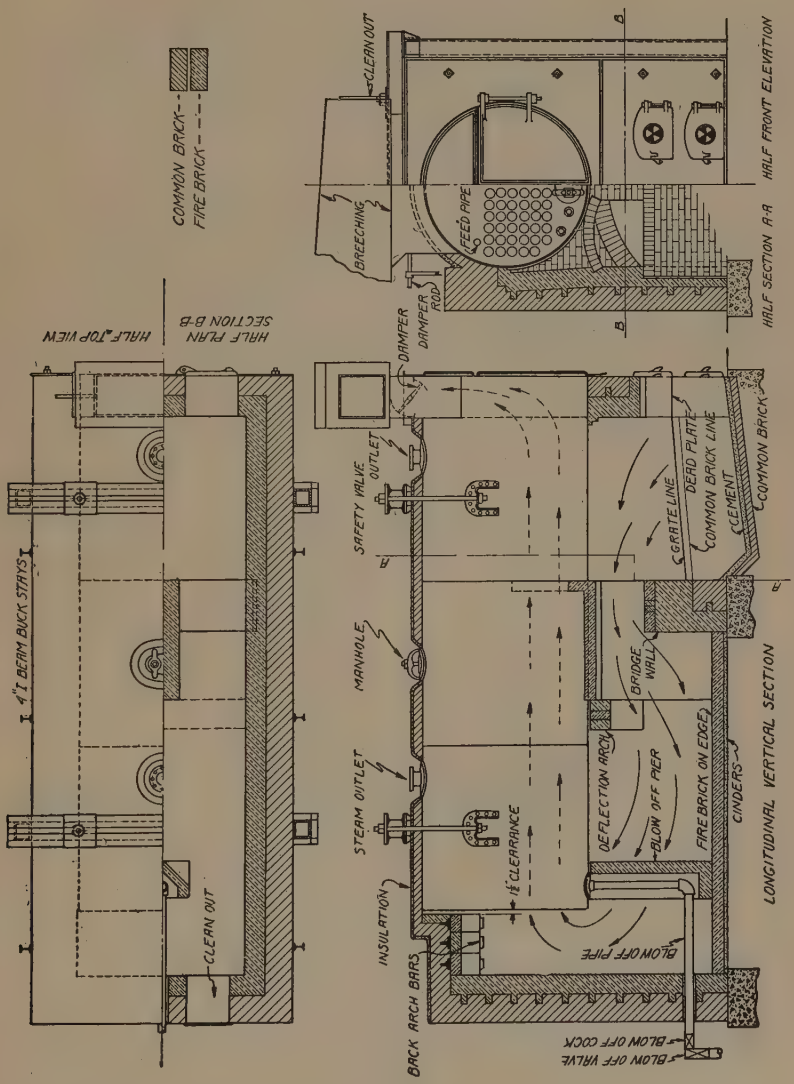
The flat ends are prevented from bulging by stays, which may be of the form shown in Fig. 12, or they may be diagonal stays. The through stays are fastened to the tube plates by means of nuts and washers as shown at *S* in Fig. 11, and also in Fig. 12. Below the water level, the end plate is stayed by the tubes. This type of boiler may be supported by brackets *B* riveted to the shell or by means of beams and columns, as shown in Fig. 14. The front bracket is often fixed in the side wall, but the rear bracket should be placed on rollers. This will prevent the straining of the plates during expansion and contraction. A small space must be left between the rear tube sheet and the brick wall to allow for expansion.

The boiler shown in Fig. 11 has two steam nozzles *N*. If the boiler has a dome, the steam nozzle is placed either at or near the top of the dome. The feed pipe may enter either at the front or at the rear. It frequently terminates in a perforated pipe below the water line. The blow-off pipe is at the rear of the boiler, as shown in Fig. 13. A valve, called the blow-off valve, regulates the flow and may be opened to blow out sediment and detached scale. The boiler is usually set with a slight inclination toward the rear so that mud and detached scale may collect near the blow-off pipe.

Fig. 12. Longitudinal Section of a Multitubular Boiler

Cleaning and Repairing. In order that the boiler may be entered for cleaning or repairs, it is provided with manholes and handholes. Fig. 11 shows a manhole *M* at the top near the middle and a handhole near the bottom of the front tube sheet. Handholes may be put in wherever desired, but manholes can be located only where the arrangement of stays and tubes will permit a space large enough for the entrance of a man. Manholes and handholes are made elliptical in shape. The former are about 11 inches by 15 inches in size, and the latter about 4 inches by 6 inches.

Heating Surface. The heating surface is the surface exposed to hot gases. In this type, the heating surface is made up of



Figs. 13 and 14. Plan, Longitudinal Section, and Cross Section of Multitubular Boiler, Showing Setting Features

about half the shell, the tubes, and about two-thirds of the rear tube sheet. In general, all the heating surface is below the water line.

Form of Setting. The complete multitubular boiler is shown in its brick setting in Fig. 14, and a longitudinal section of the setting in Fig. 13. The brick setting consists of brick laid in cement or mortar. The bridge and the portions of the furnace exposed to the fire are lined with fire brick, laid in fire-clay mortar. The bridge is built at the rear of the grate and forms a support for the grate bars; it also directs the flames upward. The arrows show the direction of the flow of hot gases. The furnace is formed by the bridge, the side walls, and the lower part of the boiler front. The boiler front is usually of cast iron with the lower part lined with fire brick. The front has doors which lead to the furnace, ash pit, and smoke box. The space below the grate is called the ash pit, and through its doors ashes are removed and a large portion of the air for combustion enters. Both the fire doors and the ash-pit doors have draft plates, or grids, to regulate the supply of air. The doors to the smoke box give access to the tubes for cleaning and repairs.

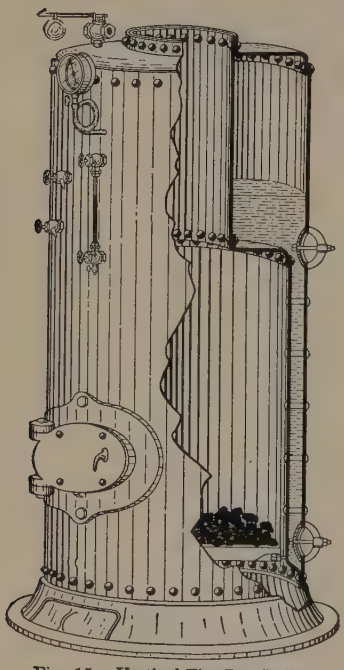


Fig. 15. Vertical Fire-Box Boiler

VERTICAL TYPE

Upright boilers are used when floor space is valuable and there is sufficient height. Small sizes are used for pile driving, supplying steam for pumps and similar work, and in hoisting engines; large sizes are used if it is necessary to have a powerful battery in a small space. In general, they are not so economical as horizontal multitubular boilers unless they are carefully designed and of considerable height. If the tubes are short, the hot gases escape before they give up much of their heat.

Single-Tube Boiler. One of the simplest forms of upright boiler is shown in Fig. 15. It has a cylindrical shell with a large fire box at its lower end. This fire box is formed by the inner cylinder, which is fastened to the outer shell by short screw stay bolts

as shown. A flanged ring connects the fire box with a large flue which conducts the hot gases away. The necessary handholes, gages, safety valves, etc., are provided. This form is not economical but is used on account of the little attention required.

Multitubular Boiler. More economical forms of the small upright boiler are illustrated in Figs. 16 and 17. The boiler shown in Fig. 16 is a common form, externally being like the boiler represented by Fig. 15, but having a somewhat different inside construc-

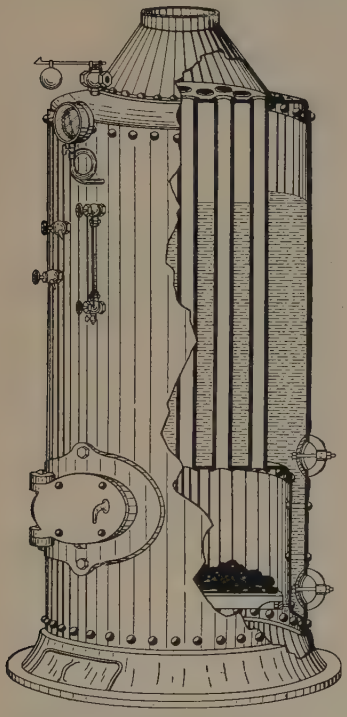


Fig. 16. Vertical Multitubular Boiler

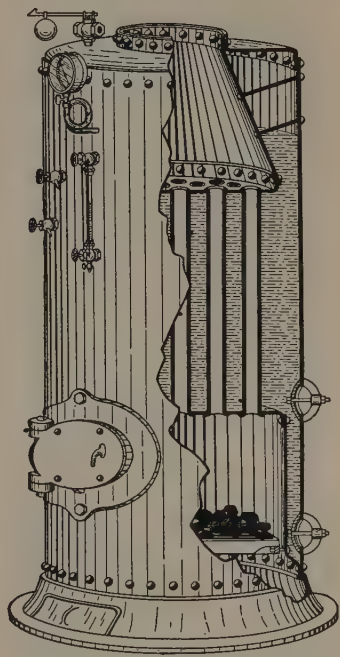


Fig. 17. Vertical Multitubular Boiler with Upper Ends of Tubes Below Water Line

tion. It resembles a multitubular boiler placed on end. The fire box is made of an inner cylinder stayed to the outer. The top of the fire box, called the lower tube sheet, is connected to the upper head by tubes, through which the hot gases pass to the smoke pipe. It will be readily seen from Fig. 16 that the upper ends of the tubes are surrounded by steam while the lower portions are covered with water. As steam is a poor conductor of heat, the ends of these tubes are liable to injury from overheating.

Fig. 18. Manning Boiler
Courtesy of The Bigelow Company

In the class of boiler shown in Fig. 17 the upper ends of the tubes are below the water level, thus avoiding the fault just described in connection with Fig. 16. The upper tube sheet is submerged, and is flanged and riveted to the frustrum of the cone which forms the smoke box. The chief defect in this boiler is that the lower part of the cone is often placed too near the shell; this is done to admit more tubes. This construction restricts the space so much that there is not sufficient room for the steam to rise as it is formed on the tubes. The cone, which is subjected to external steam pressure, is likely to be weak and should be carefully stayed.

These small upright boilers require no brick setting, as the fire box is within the boiler and the cast-iron foundation forms the ash pit.

Manning Boiler. The Manning boiler is illustrated in Fig. 18. It is, in general, similar to the upright boiler shown in Fig. 16, but in order to get a large heating surface, it is made 20 to 30 feet high. At the lower portion, the shell is of greater diameter than at the top in order to provide a large grate area. The inner fire box is stayed to the shell by screw stay bolts. As

the fire box is surrounded by water and there are many long tubes, there is a large heating surface. The tubes are arranged in concentric circles with a space for circulation in the middle.

The external fire box is joined to the shell by a double-flanged ring as shown in Fig. 19; or by the cone-shaped section as illustrated in Fig. 20. The top edge of the internal fire box is riveted to the lower tube sheet, which is flanged. The bottom of the inner fire

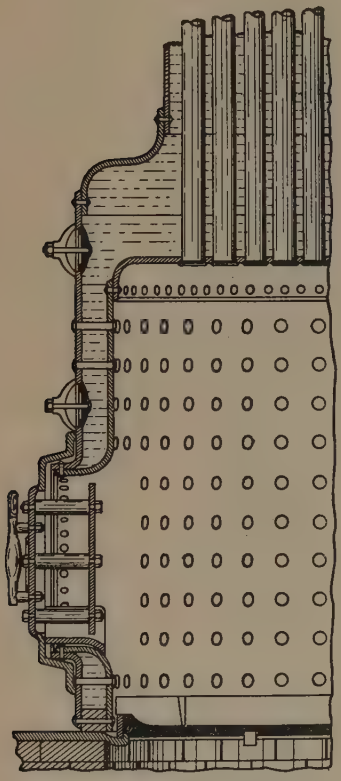


Fig. 19. Manning Boiler Details

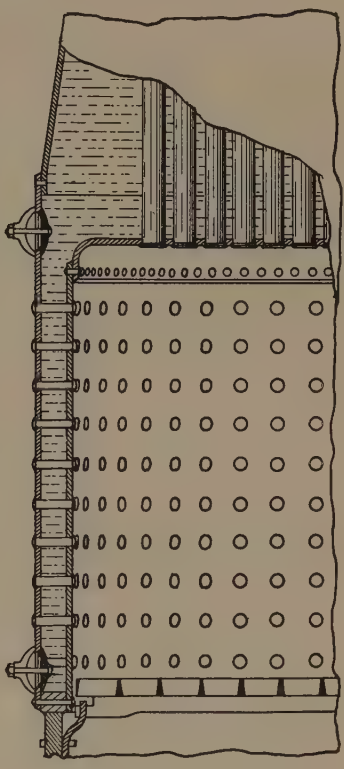


Fig. 20. Manning Boiler Details

box is connected to the outer shell by a welded ring, shown in section in Figs. 19 and 20, called the foundation ring. The water space between the inner and outer fire-box plates, called the water leg, should be large.

This boiler is cleaned by means of handholes. They are placed in the shell plates near the lower tube sheet, in the external fire box

just over the furnace door, and at the bottom near the foundation ring. As there are no manholes for cleaning, the boiler is suited to good feed water only.

The feed pipe enters the shell at the side near the middle of the water space, and extends across the boiler; it is perforated to distribute the water.

The heating surface consists of the inside of the fire box and the tubes up to the water level, and the tube sheet. That part of the tubes above the water line is the superheating surface; that is, the heat from the gases passes through the metal of the tubes to the steam, thus raising its temperature without raising its pressure. Steam heated under these conditions is called "superheated steam". In small vertical boilers this superheating surface is not desirable because the work of the small boiler does not require superheated steam and the tubes are likely to be burned by the intense heat. With the long tubes of the Manning, the gases are not as hot when they reach the top, and as this boiler is built in fairly large sizes, 200 horsepower being common, the engines supplied are built for economy, and require dry if not superheated steam.

INTERNALLY-FIRED MARINE TYPE

RETURN-TUBULAR BOILERS

Horizontal—Many Small Fire Tubes. The boilers hitherto described are used mainly for stationary work, the exceptions being so few that they need not be even mentioned. However, there is another modification of the fire-tube boiler which is now extensively used in marine work. The parts of the return-tubular boiler are essentially the same as those of flue boilers (Cornish and Lancashire) and of the multitubular boiler. They are, however, arranged differently in order to be used on board ship.

Earliest Forms. The earliest forms of marine boilers, working with pressures of 15 to 30 pounds per square inch, were square or box-shaped. They were economical and of convenient form for ships. When higher steam pressures became necessary, the flat surfaces required so much staying that they were abandoned and the cylindrical type was introduced, as this form is the best of the practical shapes to resist internal pressure. The cylindrical form

may not be as conveniently stowed aboard ship, but it will stand much higher pressures. The cylindrical marine boiler is frequently built for 200 pounds per square inch working pressure.

Single-Ended Single-Flue Type. The single-ended return-tubular boiler, shown in Fig. 21, combines the internal furnace flue of the Cornish type and the numerous small fire tubes of the multi-tubular. The cylindrical shell is made up of plates riveted together and to the flat ends of the boiler, which are flanged to fit the shell.

Furnace. The furnace is cylindrical, 3 to 4 feet in diameter, and about 7 feet in length. The front end of the furnace flue is riveted to the front end plate, which is flanged for the purpose. The back end is riveted to the combustion chamber plates. For-

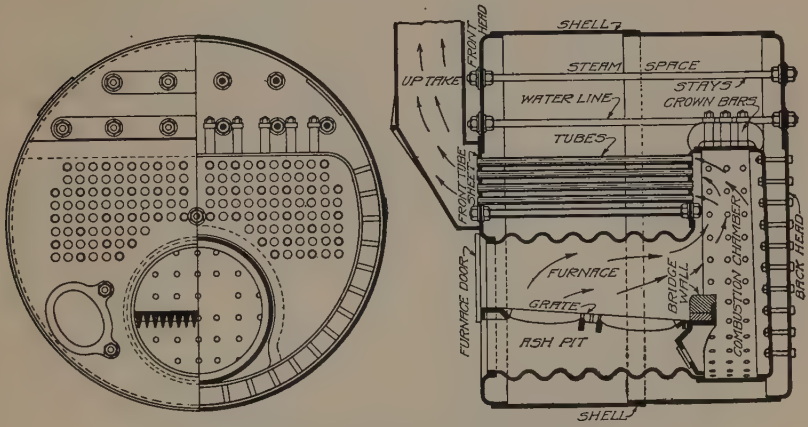


Fig. 21. Return-Tubular Boiler. Early Form

merly, the flue was a plain cylinder, but as a plain cylinder, unless of small diameter, cannot stand much external pressure, it soon became necessary to strengthen it. This was done by means of the curved ring shown in Fig. 5 and other methods; at present the corrugated flue is used, one form being shown in Fig. 6.

Grate. The grate is placed at about the center of the height of the furnace flue; the space above this grate is occupied by the fire and hot gases, while below is the ash pit. As will be seen from the arrows in Fig. 21, the hot gases fill the space above the fire, the combustion chamber, the tubes, and the uptake.

Combustion Chamber. The combustion chamber, in which the products of combustion are burned, is formed of flat and curved

plates flanged at the edges and riveted together. The shape of the plates is shown in Fig. 21, which is a sectional view of a single-ended marine boiler. The back tube sheet forms the front of the combustion chamber. The space around the tubes, furnace flue, and combustion chamber is filled with water, the water level being 6 to 8 inches above the top row of tubes. The space above the water level is called the steam space.

Stay Rods. As the return-tubular boiler has several flat surfaces, this type requires careful staying. The flat ends above the water

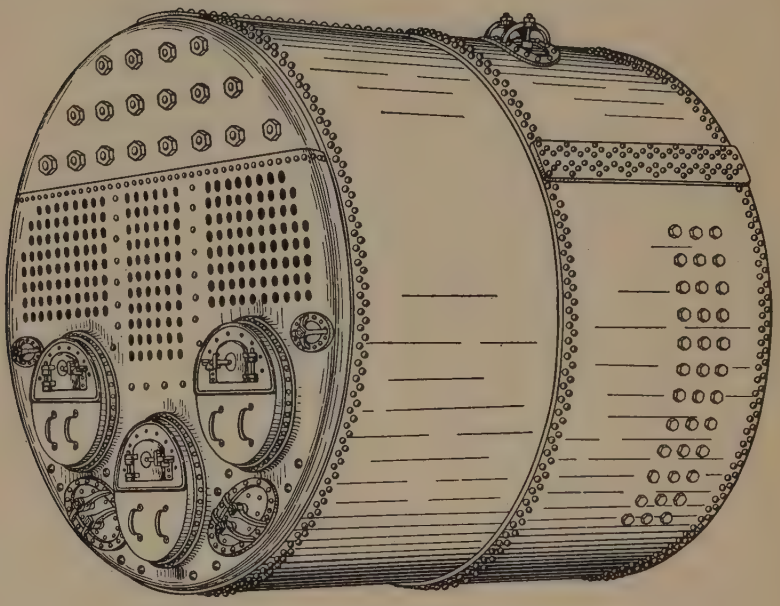


Fig. 22. Return-Tubular Boiler with Three Flues

level are prevented from bulging by long stay rods similar to those in the multitubular type. Below the water level, the furnace flue and the tubes aid in holding the flat plates in position. Moreover, a few of the tubes, shown by the heavier circles in Fig. 21, are made thicker so that a thread may be cut on the ends, which are screwed into the tube sheets and held by thin nuts. The combustion chamber plates are stayed to the rear end plate and the shell by short screw stay bolts. The flat top of the combustion chamber is supported by girders or crown bars.

Single-Ended Multiple-Flue Type. The boiler shown in Fig. 21 has only one furnace, but return-tubular boilers frequently have two, three, or four furnaces.

Fig. 22 shows a boiler with three furnaces. Large furnaces are more efficient than small ones because the grate area increases directly as the diameter, while the air space above the grate increases as the square of the diameter. The greater space aids combustion. The length of the grate bars is nearly constant for all sizes of flue because it is limited by the distance a fireman can throw coal. Furnace flues are usually from 36 to 54 inches in diameter. As the size of furnaces is fixed, the number depends upon the size of the boiler, for a large boiler must have a large grate area, which can be obtained only by using several furnaces. The various arrangements are shown diagrammatically in Fig. 23.

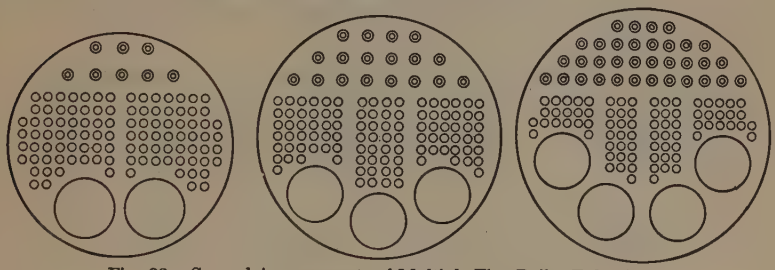


Fig. 23. Several Arrangements of Multiple-Flue Boiler Tube Sheets

Arrangement of Combustion Chambers. A single-furnace boiler has but one combustion chamber. A two-furnace boiler may have a combustion chamber for each furnace or it may have a common combustion chamber. It is better to have a common combustion chamber for the two furnaces, because alternate stoking keeps up a more nearly constant pressure of steam and there is less smoke. Three-furnace boilers usually have three combustion chambers, while four-furnace boilers have two. In case four furnaces are used with three combustion chambers, the two center furnaces lead to a common combustion chamber and each outside furnace has one.

Double-Ended Type. This form of marine return-tubular boiler is practically the same as two single-ended boilers placed back to back, but with the rear plates removed. The weight of the rear plates is saved, and there is less loss from radiation. This makes the double-ended boiler lighter and cheaper in proportion to the

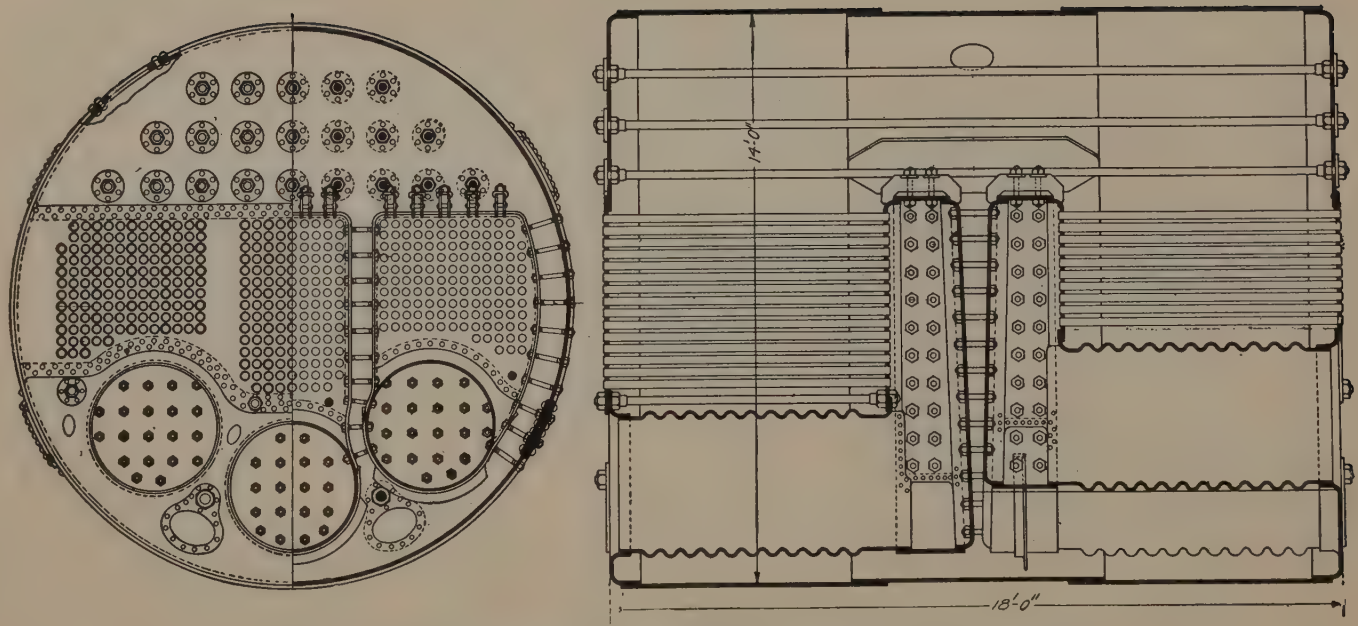


Fig. 24. Vertical and Longitudinal Sections of Three-Flue, Double-Ended, Return-Tubular Boiler

heating surface. Double-ended boilers are often made 16 feet in diameter and 18 feet long.

There are two distinct classes of double-ended return-tubular boilers—those having all the furnaces open into one combustion chamber and those having several combustion chambers. The boiler having but one combustion chamber has the disadvantage that if one fire is being cleaned the whole boiler may be cooled by the inrush of cold air. It is better to have a combustion chamber for each furnace, or at least to have a combustion chamber for the furnaces of each end. The usual method of dividing up the combustion chambers is by water spaces, as shown in Fig. 24 which shows sections of a boiler having a combustion chamber for each furnace.

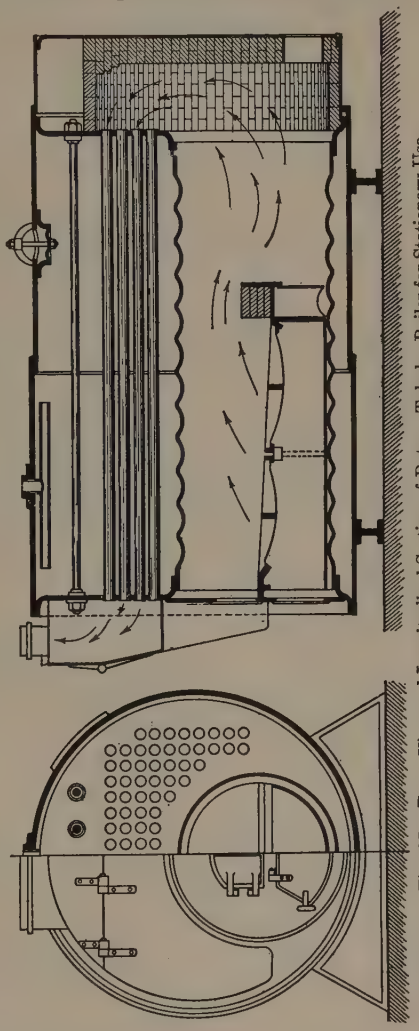


Fig. 25. Front View and Longitudinal Section of Return-Tubular Boiler for Stationary Use

Stationary Return-Tubular Type. While the return-tubular boiler is commonly used in marine work, this type, with some changes in detail, is used in stationary plants. Fig. 25 shows the construction and arrangement of parts. The flue is larger in proportion to the diameter than is the case with the marine form; the combustion chamber is partly external to the shell; that is, the rear tube sheet is also the rear end plate. This arrangement does away with the necessity of staying the flat plates of the combustion chamber.

Another form of internal-furnace return-tubular boiler is shown in Fig. 26. This boiler usually has two flues extending from the front to the back head. The grate is placed in the corrugated portion, while conical water tubes support the flue back of a bridge wall. The large furnaces and the space around the conical tubes provide a combustion chamber of ample size.

The arrows show the direction taken by the hot gases. After leaving the internal flue they enter the return tubes, which are below the furnace; before leaving the boiler, they pass underneath the

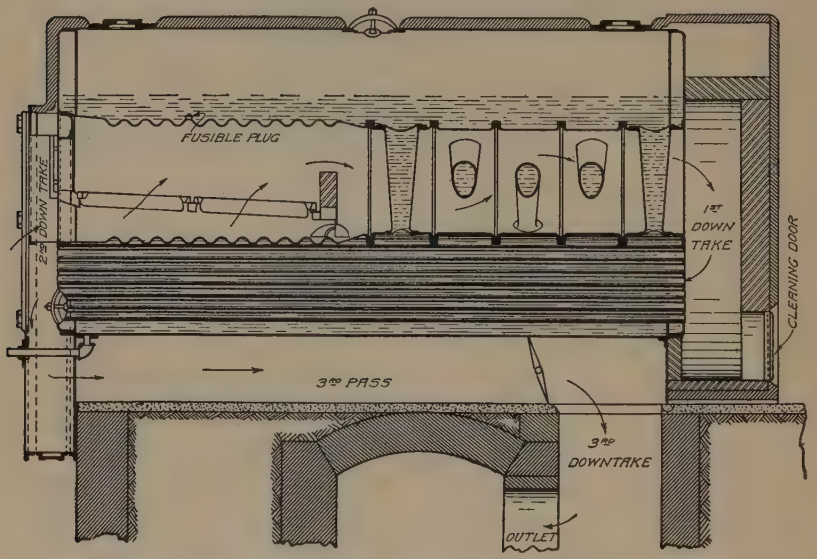


Fig. 26. Stationary Boiler of the Return-Tubular Type

shell. By this arrangement the hotter gases are near the water line and the cooler gases in contact with the cold water. Thus there is the greatest difference in temperature at all times. At each change in the direction of the hot gases, there is an opportunity for dirt and ash to fall by gravity, so that the tubes may remain clean and efficient.

With the exception of the foundation there is no brickwork. The shell is covered with a non-conducting material. This boiler, like the Galloway, has a large steam and water space, thus insuring dry steam and great reserve power.

THROUGH-TUBE BOILERS

Horizontal—Many Small Fire Tubes. Vessels of light draft require a boiler of small diameter. This is especially true of gunboats, as it is desirable to have the boilers below the water line. As there is not room for the return-tubular boiler, the through-tube, shown in Fig. 27, is sometimes used. This boiler is made up of the same parts as the return-tubular, the chief difference being that of arrangement. The rear plate of the combustion chamber forms one tube sheet and the end plate forms the other. The top of the combustion chamber is stayed to the shell by sling stays, which are bars having forked ends fastened to the shell and to the combustion chamber.

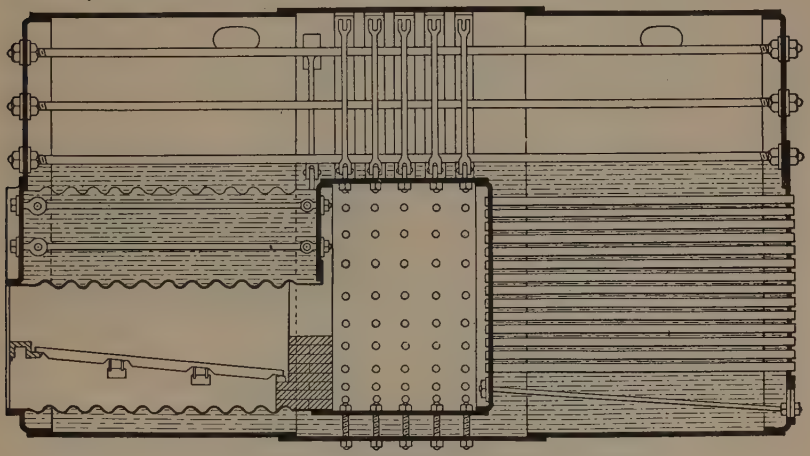


Fig. 27. Through-Tube Boiler. Longitudinal Section

The fire is in a flue, or flues, which leads to the combustion chamber. The hot gases pass from the combustion chamber through the tubes to the uptake at the back end. The chief objection to this form is its length, for the heating surface is small unless the boiler is made very long.

FIRE-BOX TYPE

LOCOMOTIVE BOILERS

Horizontal—Small Fire Tubes—Externally-Fired. Although vertical fire-tube boilers may be classed as fire-box boilers, yet the name fire-box boiler is usually applied to the locomotive type whether used with a locomotive or as a stationary boiler.

The usual form of horizontal fire-box boiler consists of a cylindrical shell, or barrel, partly filled with tubes, and a rectangular fire box. The shell is prolonged beyond the rear tube sheet to form a smoke box. The front ends of the tubes open into the fire box, while the rear ends open into the smoke box. The hot gases from the fire pass through the tubes to the smoke box, and thence to the stack or uptake. For locomotive work, there is a large number of small tubes, usually 2-inch, but for stationary work the tubes are larger and less numerous. The reason for this difference is that in the locomotive boiler a greater heating surface is necessary, and to obtain sufficient draft to burn the large amount of coal for this

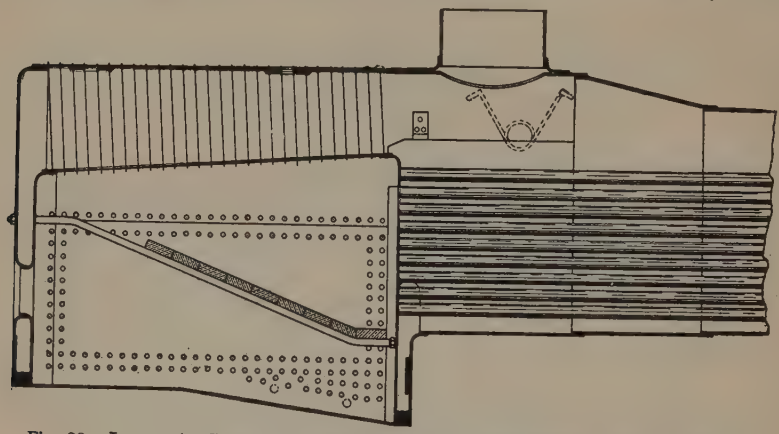


Fig. 28. Locomotive Fire-Box Boiler Showing Tube Across Fire Box to Support Tile for Furnace Arch

heating surface, the exhaust steam is turned into the smoke box. The blast of steam carries the heated gases up the stack and a fresh supply of air passes through the grate.

The cylindrical shell is joined to the fire box by riveting to a flanged ring or to a cone-shaped portion, as in the vertical boiler. The fire box has a rectangular cross section and usually a flat top. Like the vertical boiler, there is an inner and an outer shell for the furnace, the inner having the same shape as the outer, except that the top is flat. The external shell is connected to the inner by short screw stays. The space between is called the water leg. The flat top is stayed by girders or crown stays. These are sometimes attached to the shell by sling stays. The lower portions of the tube

sheets are held in place by the tubes; the upper portions are stayed by diagonal stays.

The chief differences in the various forms of locomotive boilers are the shape of the fire box and the location of the grate. Locomotive boilers are either straight top or wagon top. The wagon top boiler, Fig. 28, has a cone-shaped portion by means of which the boiler is larger at the fire-box end. This construction is to give a greater steam space. The increase in size of boilers has raised the top so high above the rails that the wagon top is not now used extensively; the straight top, Fig. 29, is more common.

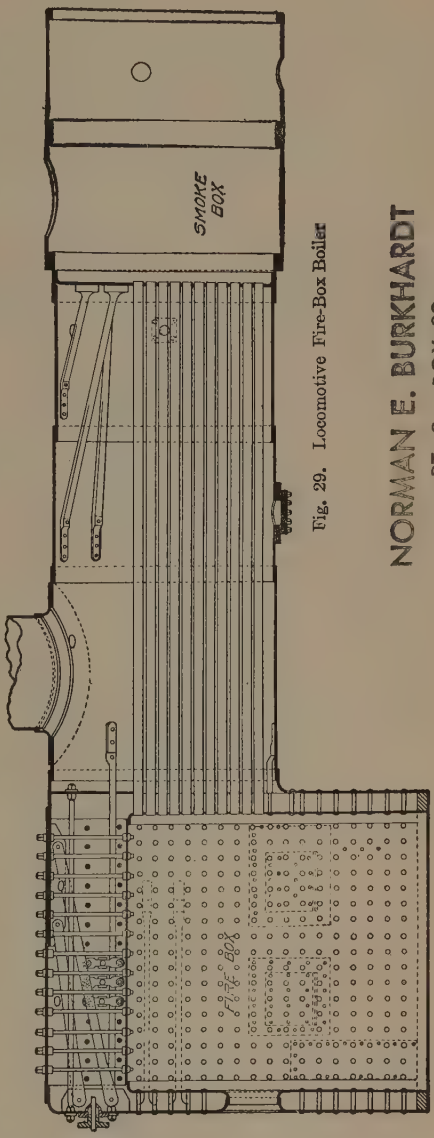



Fig. 29. Locomotive Fire-Box Boiler

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RT. 3 - BOX 89
FRAZEYSBURG, OHIO 43822

Belpaire Boiler. The shell and fire tubes of this type of boiler are practically the same as in any other fire-box boiler; the peculiarity lies in the fire box. The inner and outer fire-box plates are horizontal at the top, and the sides of the outer fire box are continued so that the space above the crown sheet is rectangular in section. The advantage to be gained by this construction is that the stay bolts, which hold the crown sheets and side sheets, can be placed at right angles to the sheets. This reduces any tendency on the part of the sheets to bend when under pressure.

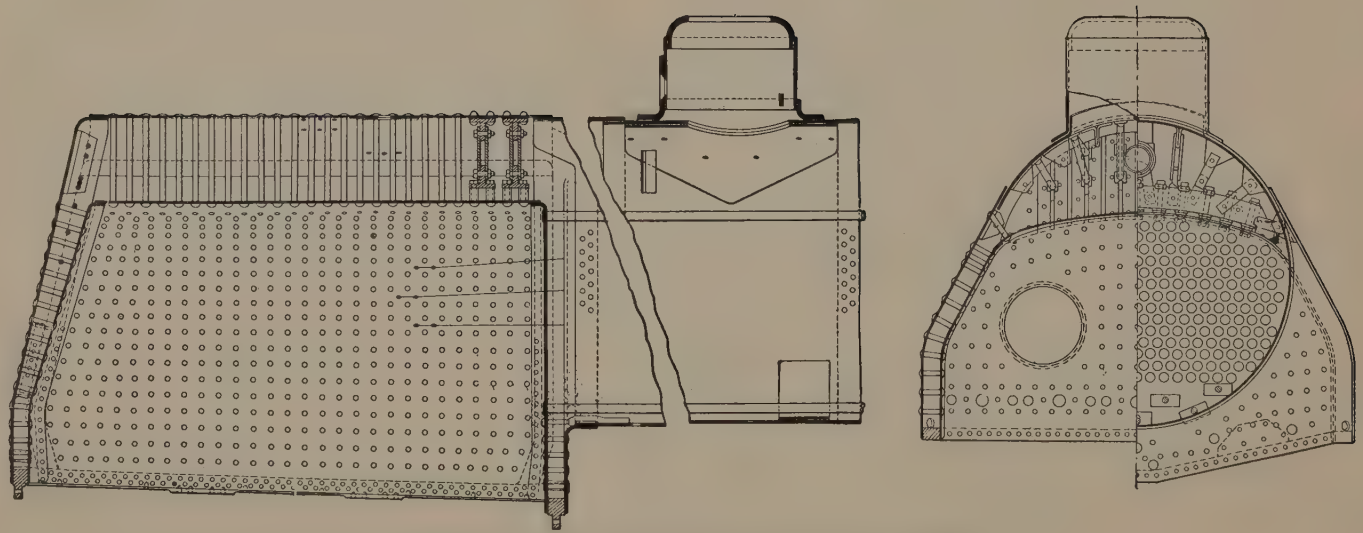


Fig. 30. Side and End Views of Wootten Locomotive Fire-Box Boiler

Wootten Boiler. In this type, also, the fire box is the chief part to be considered. The size of the locomotive fire box is limited. With older types the width was limited to less than 3 feet and the length to less than 7 feet. This was because of the frames and the distance between the axles. By placing the fire box above the axles, the width was increased by an amount equal to the thickness of the frames, or about 7 inches, and the length increased to about 11 feet. By the method of supporting the fire-box end of the boiler on trucks, the width can be still further increased.

Fire Box. A broad, shallow fire box is required if anthracite coal is used. The Wootten fire box, shown in Fig. 30, is very

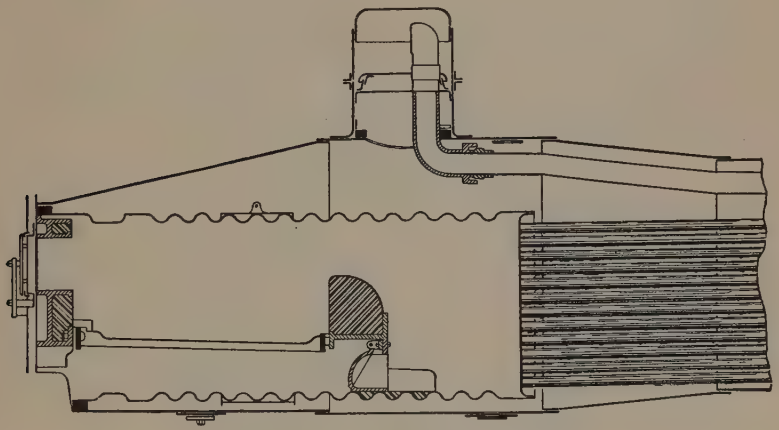


Fig. 31. Lentz Locomotive Fire-Box Boiler

wide and is placed on top of the driving wheels. Formerly, a combustion chamber was placed between the end of the grate and the tubes, but, as it was found to be unnecessary, it is not now used.

Lentz Boiler. The object of the design shown in Fig. 31 is to avoid the use of stays. To do this, no flat plates are used except the tube sheets, and these are stayed by the tubes. The fire box is in the form of a corrugated flue similar to those in internally-fired return-tubular boilers. As this is circular it requires no stays. The shell is circular and shaped as shown in the illustration. This type has been much used in Europe, but only a few have been built in this country.

STATIONARY BOILERS

General Fire-Box Type. The fire-box boiler, usually called the locomotive boiler, is often used for stationary work, traction engines, and for vessels of light draft. This type of boiler, slightly modified, is sometimes used for generating the steam for heating buildings. It is economical and durable when used with natural draft. The chief differences in construction are larger tubes because of the draft, and the changes due to method of support. A common

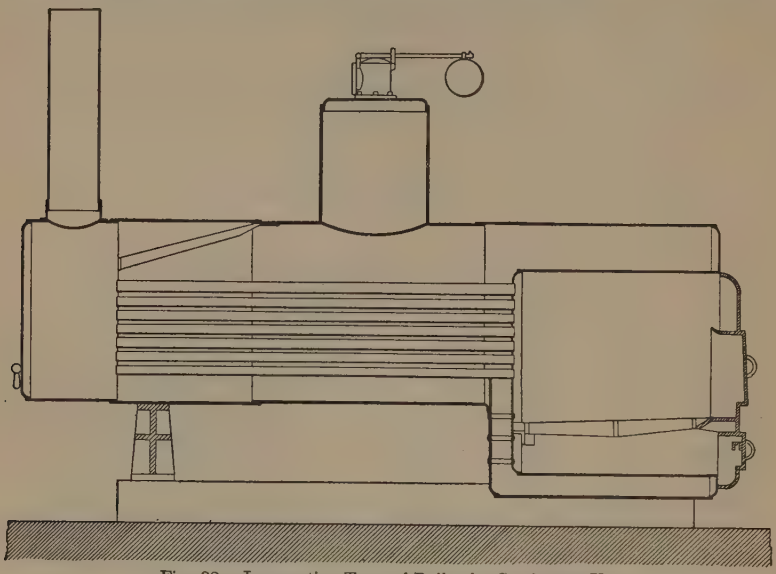


Fig. 32. Locomotive Type of Boiler for Stationary Use

form is shown in Fig. 32. This type has been built in large sizes for high pressure, but when so made is expensive.

PECULIAR FORMS

Return-Tubular Fire-Box Boiler. Boilers of the form shown in Fig. 33 resemble the locomotive fire-box type, but in addition have return tubes. The hot gases reach the uptake by means of these tubes instead of passing to the chimney from the smoke-box end. Thus they combine the advantages of the fire-box type and the return-tubular type without the brick setting. The water surrounds the furnace on all sides except the front. They are built in sizes from 12 to 70 horsepower. As Fig. 33 shows the construction so clearly, further description is unnecessary.

Cochrane Vertical Boiler. The Cochrane vertical boiler is somewhat like the return-tubular boiler in point of arrangement of

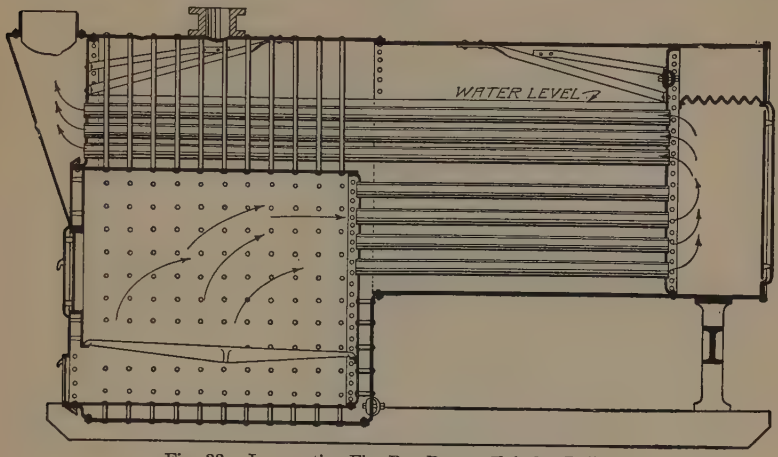


Fig. 33. Locomotive Fire-Box Return-Tubular Boiler

heating surface. This boiler is shown in section in Fig. 34. The hot gases pass from the furnace to the combustion chamber, then through the tubes to the uptake. The heating surface consists of tubes and the plates of the fire box, which is surrounded by water except at the bottom. The crown of the boiler and of the fire box, being hemispherical, require no staying. The hemispherical crown also allows a large steam space. The flat plates (the tube plates) are held together by the tubes.

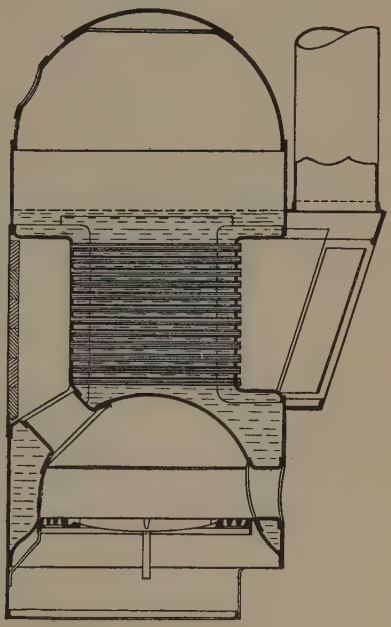


Fig. 34. Cochrane Vertical Boiler

Shapley Boiler. The Shapley boiler, shown in Fig. 35, may be called a return-flue vertical boiler. The upper portion is a reservoir for water and steam, and the lower contains the fire box. The crown sheet of the fire box is

stayed to the top by through stays. The hot gases from the fire rise in the fire box and pass through short horizontal tubes to an annular space. This annular space is connected to the flue at the base by vertical tubes passing through the water space.

This boiler has a large combustion chamber; the fire box is surrounded by water, and the crown sheet and tubes are removed from the intense heat of the fire. This arrangement increases the

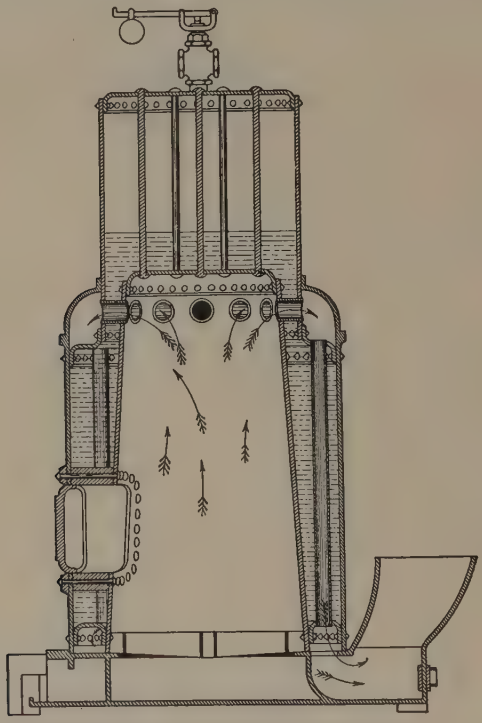


Fig. 35. Section of the Shapley Vertical Boiler

heating surface, allows good combustion, and results in a durable boiler. The base is partly filled with water, so that any sparks carried over will be quenched.

Brady Scotch Boiler. The Brady Scotch Boiler, Fig. 36, is a modification of the well-known standard marine boiler, and combines the advantages of internal firing with some virtues of its own. The lower shell contains two corrugated flues, one being shown in part section in the figure; the flues lead into a chamber at the back

of the shell from which a large number of fire tubes extend over the flues, thus leading the heat to the stack at the front of the boiler. The upper drum, which is connected to the lower shell by large necks at front and rear, is kept about one-third full of water.

In the Brady boiler, positive circulation is obtained by an annular ring placed around the inside of the shell, with an opening

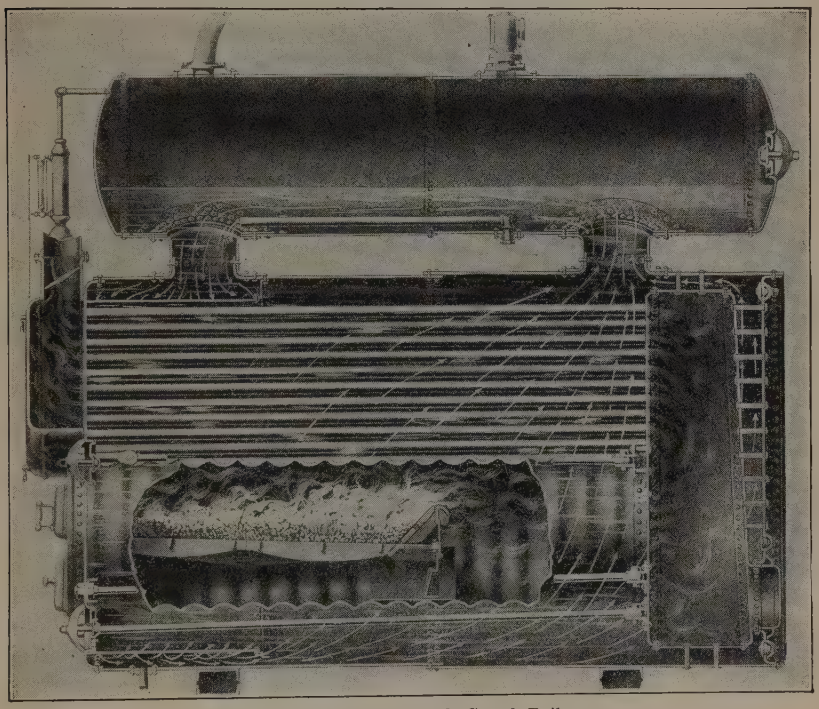


Fig. 36. Section of Brady Scotch Boiler
Courtesy of International Engineering Works, South Framingham, Massachusetts

at the bottom. (Shown by white line and arrows curving upward at bottom of Fig. 36.) As the front neck of the upper drum leads into the annular space the water is compelled to pass around the shell to the base of the boiler, where it rises around the flues and between the tubes to the rear, back of the upper drum as shown by the arrows in Fig. 36, thus establishing the proper circulation and overcoming a difficulty in Scotch marine boilers which sometimes have poor water circulation.

The Brady boiler, being internally-fired, requires no brick setting and, as the hot gases in the flues and tubes are at all times surrounded by water, the losses from radiation are reduced to a minimum. Standard manholes and handholes are provided, allowing a thorough inspection and cleaning of all parts of the boiler without difficulty. The boilers are suitable for both marine and stationary work.

Directurn. The Begg's "Directurn" boiler, Fig. 37, is, in brief, a horizontal, externally-fired, return-tubular boiler in which tubes conduct hot gases through the space behind the bridge. This

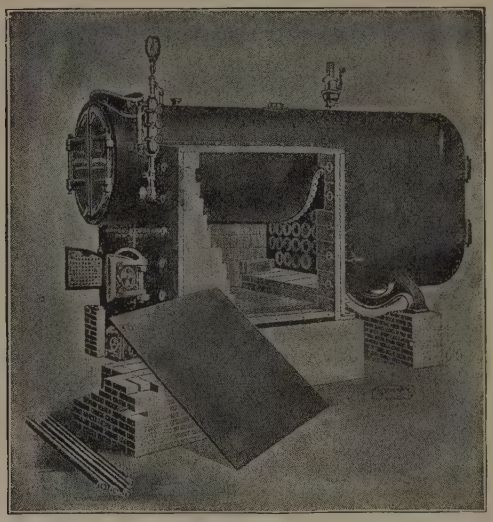


Fig. 37. "Directurn" Externally-Fired Return-Tubular Boiler
Courtesy of James Beggs and Company, New York City

boiler consists of a shell partly filled with 3-inch tubes. The rear of the furnace is a throat sheet in which 4-inch tubes are expanded. The other ends are expanded into the rear end plate, which is made large enough for the purpose. The furnace is encased in steel plates lined with fire brick held in place by rods passing through the notches as shown. The manhole for entering the boiler is placed in the front head instead of in the shell, as is frequently done. A number of other makes of this type of boiler have been developed. The "Economic", Fig. 38, manufactured by the Erie City Iron Works, Erie City, Pennsylvania, is a notable example.

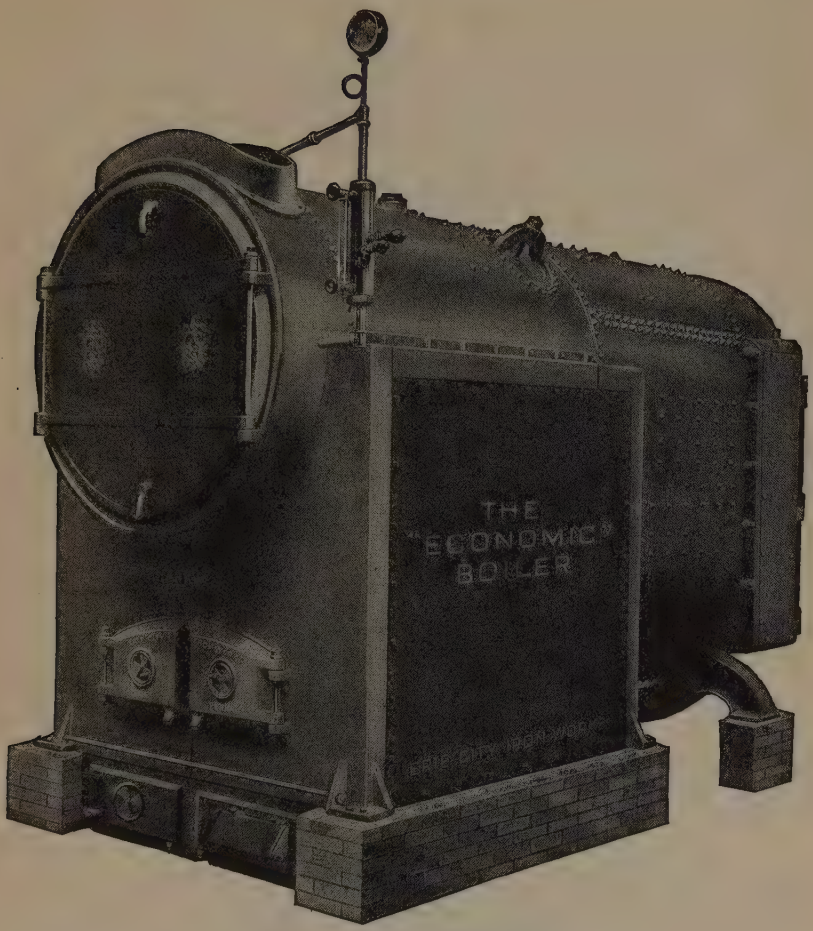


Fig. 38. "Economic" Directurn Boiler
Courtesy of Erie City Iron Works

WATER-TUBE BOILERS

General Characteristics. Water-tube boilers differ essentially from fire-tube boilers, the names indicating the chief points of difference. In the fire-tube boiler, the tubes, which are surrounded by water, conduct the hot gases to the smoke box. In the water-tube, the tubes are filled with water, and the hot gases pass over and among them on their way to the chimney.

Although flue boilers and the tubular types were introduced at an earlier period than the water-tube, yet the last-named type is

not a new form of steam generator. About a century ago, John Stevens invented a water-tube boiler and fitted it to a steamboat. This boiler, Fig. 39, was a combination of small tubes connected at one end to a reservoir. Thus the "Porcupine" was one of the earliest forms. At various times since then many ideas have been worked out both for marine and stationary boilers. During the last twenty-five years, however, the water-tube boiler has been steadily growing in favor, the chief reasons being the necessity of higher steam pressures, larger capacities, greater reliability of materials, greater skill in design and workmanship, and more intelligent management.

It is not within the province of this article to discuss the relative merits of fire-tube and water-tube boilers, but a careful

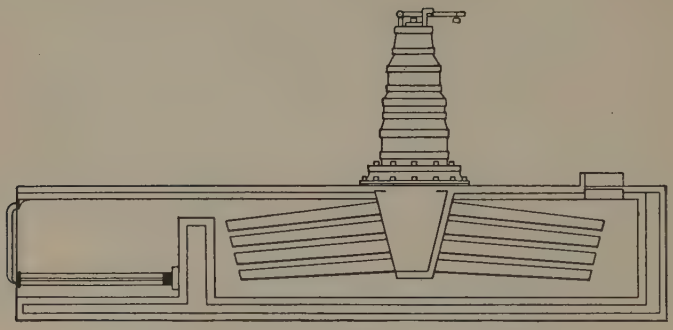


Fig 39. Diagrammatic Sketch of Stevens Boiler

impartial consideration seems to show that as far as economy of running is concerned there is but little difference, providing conditions exist permitting the use of either type. The fire-tube boiler is reliable and can be handled by those possessing comparatively little knowledge of engineering; its chief defect seems to be the disastrous results following an explosion. The water-tube boiler, on the other hand, is safe, and suited to higher pressures, but in some cases requires greater manual labor in operation.

Advantages. Before discussing these boilers in detail, let us consider briefly the salient points.

Safety. Probably the greatest advantage claimed for the water-tube boiler is its safety. The boiler contains much less water than does the flue or tubular boiler, and the water is divided

into small masses, thus minimizing serious results in case of rupture. On account of the shape and arrangement of parts, the circulation is usually good, and no part exposed to the fire can be uncovered while there is a reasonable quantity of water in the boiler.

Rapidity in Raising Steam. The many small streams into which the water is divided as it passes through the furnace greatly facilitate the absorption of heat. Because of the small streams and the rapid circulation, the water is converted into steam in a relatively short time. Several hours, usually 5 to 7, are required to raise steam to working pressure in a tubular boiler, while in many water-tube boilers steam can be raised to over 200 pounds pressure in less than half an hour.

Durability. Most water-tube boilers are so designed that no seams are exposed to the fire or hot gases. Seams are the weakest part of a boiler and, as strains due to unequal expansion concentrate at such points, leaks, or even ruptures, are liable to occur if seams are exposed to the fire. In the water-tube boiler, the joints between tubes and tube sheets are not in the direct path of the hot gases.

Loss of Heat. The loss of heat will evidently be reduced to a minimum if the heating surface is clean and thin. The small diameter of the water tubes (2 to 4 inches) allows the use of thin metal which does not hinder the transmission of heat. The rapid circulation in the water-tube boiler prevents the accumulation of sediment, which is a poor conductor of heat. Still further, dust and dirt do not readily collect on the convex surface of water tubes, but the inside of fire tubes soon becomes choked with soot unless cleaned frequently, Fig. 40. It will be noted that the fire-tube type offers no choice as to the manner the gases are presented to the heating surface; they must pass *through* the tube longitudinally, while in water-tube boilers the gases may be forced to travel longitudinally with the tubes or compelled to cross them transversely.

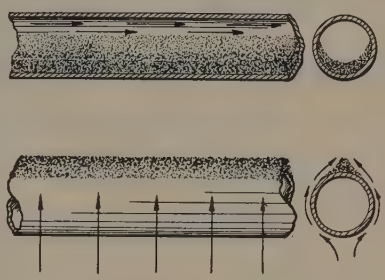


Fig. 40. Collection of Soot in Fire-Tube and Water-Tube Boilers

Less Weight. It is a well-known fact that a cylinder of large diameter must be much thicker than one of small diameter when

the internal pressure is the same. The thickness of the shell of a fire-tube stationary boiler is not excessive, because of the moderate diameter; but in the return-tubular marine boiler, the shell plates for 250 pounds pressure would be about $1\frac{7}{8}$ inches thick. The difficulty of working such thick plates and their great weight render the cylindrical boiler unsuitable for high pressures. The small tubes and drums of the water-tube boiler may be made quite thin even for very high pressures. In general, it may be said that, for the same capacity and pressure, the weight of a water-tube boiler is only about two-thirds that of a fire-tube.

Classification. Many attempts have been made to classify water-tube boilers. By some writers a classification based on circulation, or on the principle of operation, is claimed to be superior to any division according to construction.

On page 4 of this article is given a classification according to features of construction. No classification is altogether satisfactory because boilers overlap into other divisions; a water-tube boiler may be sectional, of the double-tube type, have horizontal tubes, straight tubes, and free circulation. In order to have some sort of classification, and as no discussion will be entered into regarding relative merits, the classification given will be here adopted and followed as closely as conditions will permit.

Water-tube boilers are divided into two great classes—horizontal and vertical. Under these heads come sectional and non-sectional, straight-tube and curved-tube, and single-tube and double-tube. If the tubes are nearly horizontal, such as is the case of the Babcock and Wilcox, Edge Moor, Heine, and others, the boiler will be called horizontal; if the tubes are vertical, or nearly so, as in the Wickes, Stirling, etc., the boiler will be classed as vertical.

Although most boilers can be classified as already outlined, there are a few of such peculiar construction and arrangement that they must be placed by themselves under "Peculiar Forms".

As it is impossible to discuss all makes of boilers, a few representative forms will be considered as types of their respective classes. No attempt will be made to choose any make as being the best, because many conditions must be considered in selecting a boiler. The boilers described, except in a few cases, are now used extensively in either stationary or marine work.

HORIZONTAL TYPES

Babcock and Wilcox. *Water Tubes Nearly Horizontal—Steam and Water Drum Horizontal—Straight-Tube—Single-Tube—Sectional.* This boiler consists of a large number of 4-inch tubes, 18

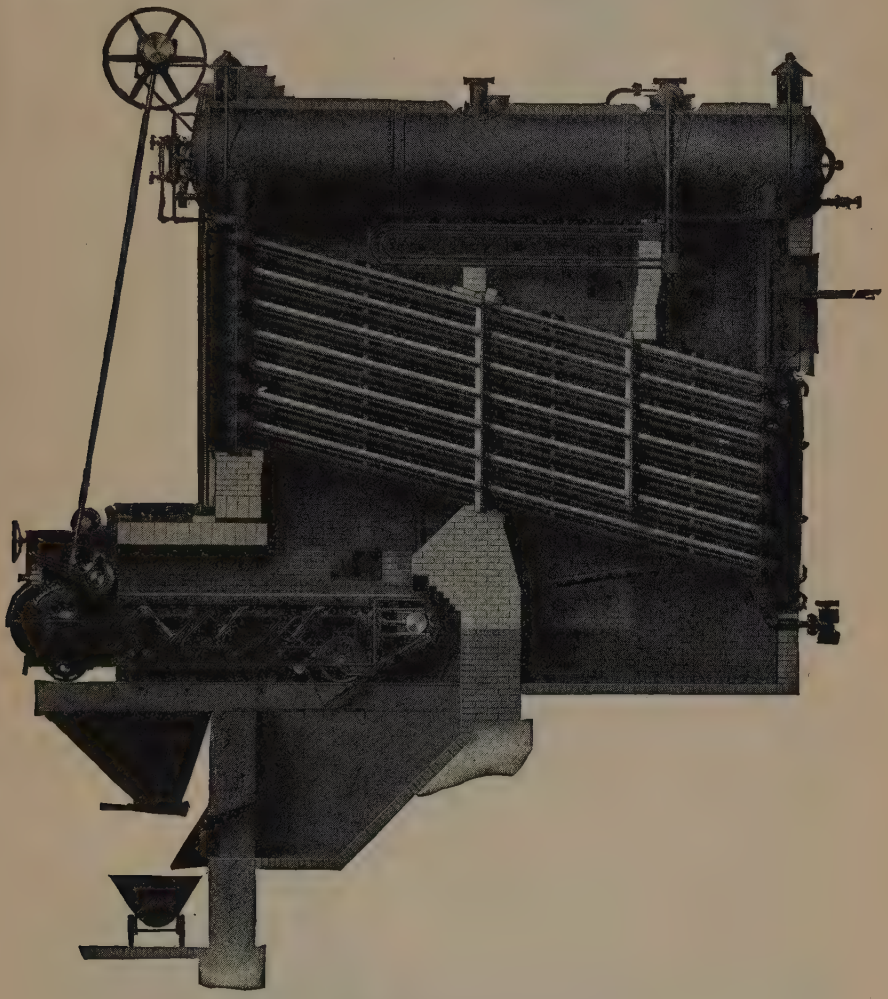


Fig. 41. Vertical-Header Longitudinal Drum B. & W. Boiler Equipped with B. & W. Superheater and Chain Grate Stoker

Courtesy of Babcock and Wilcox Company, New York City

feet long, connected to one another and to a horizontal steam and water drum. The arrangement of the parts is shown in Fig. 41, which is a side view of a much-used form of this boiler.

Each tube is expanded into a header of the form shown in Fig. 42. The tubes in a vertical row enter one piece, and this vertical row is independent of the others, thus making it a sectional boiler, with a "staggered" arrangement of the tubes. In the back side of the front header, and in the front side of the rear header, holes are drilled into which the water tubes are expanded. In the front side of the header opposite each tube is a handhole fitted with a handhole plate. The details of construction are shown in Fig. 43. The tops of the headers are connected to the steam and water drum by short tubes, and the same construction is used for connecting the mud drum to the rear header.

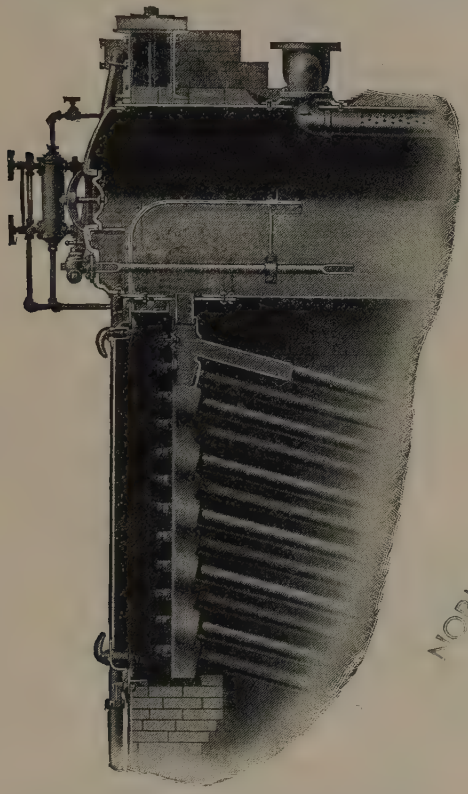
Fig. 42. Wrought-Steel Vertical Header for B. & W. Boiler

Operation. The grate is at the front end of the boiler under the higher end of the tubes. The hot gases from the fire are guided by division plates and bridges, so that after rising from the grate they pass up between the tubes; the gases then pass downward among the tubes and, after rising a second time, pass off to the chimney. In this way, the direction of the currents of hot gases is at all times almost at right angles to the tubes, thus impinging upon them instead of passing parallel to the heating surfaces, as in the case of fire tubes. As the gases impinge three times against the staggered tubes, the heating surface is very efficient.

Fig. 43. Handhole Fittings for B. & W. Boiler

Circulation. The feed water enters the steam and water drum through the pipe shown in Fig. 44. It is thus heated before it mixes with the hot water in the boiler.

As the water in the tubes becomes heated, it rises to the higher end, where it is partly converted into steam; a column of water and steam rises through the header to the drum, in which the steam and water become separated. The cooler water at the rear of the steam and water drum flows down into the lower end of the tubes and, as it becomes heated, rises. Thus there is a continuous circulation.



NORMAN E. BURKHARDT
RT. 3 - BOX 89
FRAZEYSBURG, OHIO 43822

Fig. 44. Partial Vertical Section Showing Method of Introducing Feed Water in B. & W. Boiler

Steam is taken from the rear end of the steam and water drum. Much of the soft scale-forming matter and mud falls to the mud drum, from which it can be blown out.

This boiler is manufactured with both cast-iron headers and forged-steel headers; with round or elliptical outside handhole plates setting on machine surfaced seats and held by steel safety clamps on the inside; and with inside handhole cover plates of elliptical

form. The forged-steel header boilers are used for the higher pressures. The marine form of this boiler has a cross drum; that is, the drum is at right angles to the tubes instead of parallel to them. It is similar in form to the cross-drum types used for stationary work. This form is used in case there is not sufficient head room.

Root. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Sectional.* This brief outline indicates that the Root water-

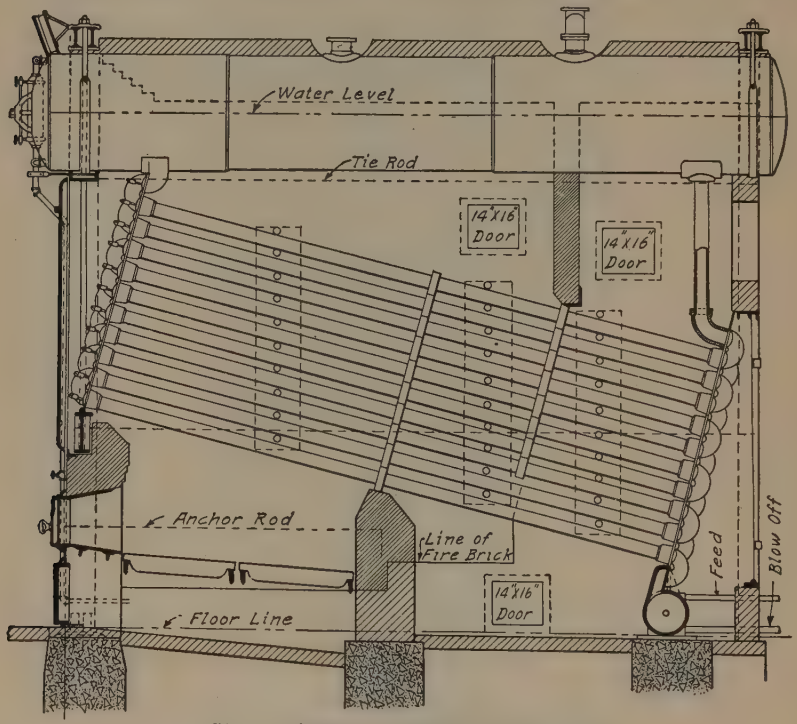


Fig. 45. Section of Root Water-Tube Boiler
Courtesy of Abendroth and Root Manufacturing Company

tube boiler is, in its main features, like the Babcock and Wilcox. In fact, the difference is in detail of construction only. Fig. 45 shows a longitudinal section of the boiler. Surrounding the tubes is the steam and water drum which has attached to the under side, near the front end, a cross box having openings on its face to receive the regular connecting bends from the top row of tubes.

Construction. The Root water-tube boiler is composed of 4-inch tubes. These tubes are expanded into cast-iron headers as

shown in *A*, Fig. 46. A vertical section is formed by placing one pair upon another as shown at *B*, Fig. 46. One tube of each pair is connected to one above it by a flexible bend, by means of which an uninterrupted circulation from the bottom to the top of the section is obtained. A metallic packing ring, *C*, *D*, and *E*, Fig. 46, insures a tight joint between the bend and the header.

To form the boiler several of these vertical sections are placed side by side. The theory is that these vertical rows are not to be rigidly connected because the lower tubes, being nearer the fire, expand more than those above.

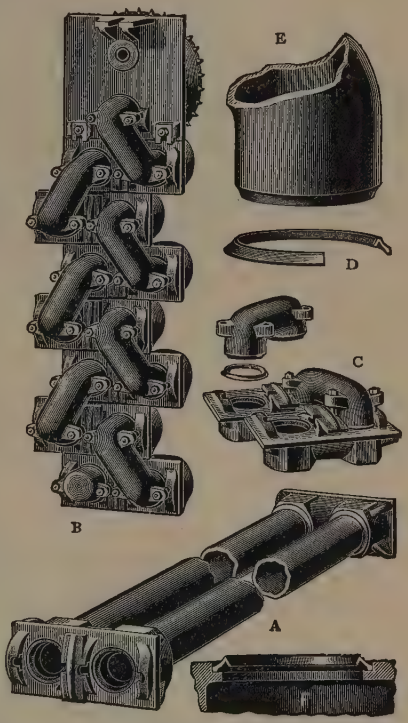


Fig. 46. Root Boiler Tube and Header Details

Circulation. Each section is connected to the cross box of the overhead drum into which the water and steam are discharged from the tubes. At the rear of the boiler a plate is riveted to the drum and bored to receive the tubes that make the connection between the drum and rear headers. The feed water enters at the top of the mud drum, upon which the rear ends of the tubes rest (see Fig. 45), and meets the hot water coming from above. The circulating water then flows from the top of the mud drum into the lower end of the tubes. As these tubes are surrounded by hot gases, the water becomes heated and rises through the tubes to the steam and water drums. This heated water contains bubbles of steam which leave the water and collect in the steam drum. The water flows back through the steam and water drum and descends through the back header to meet the entering feed water. The water level is kept at about the middle of the steam and water drums.

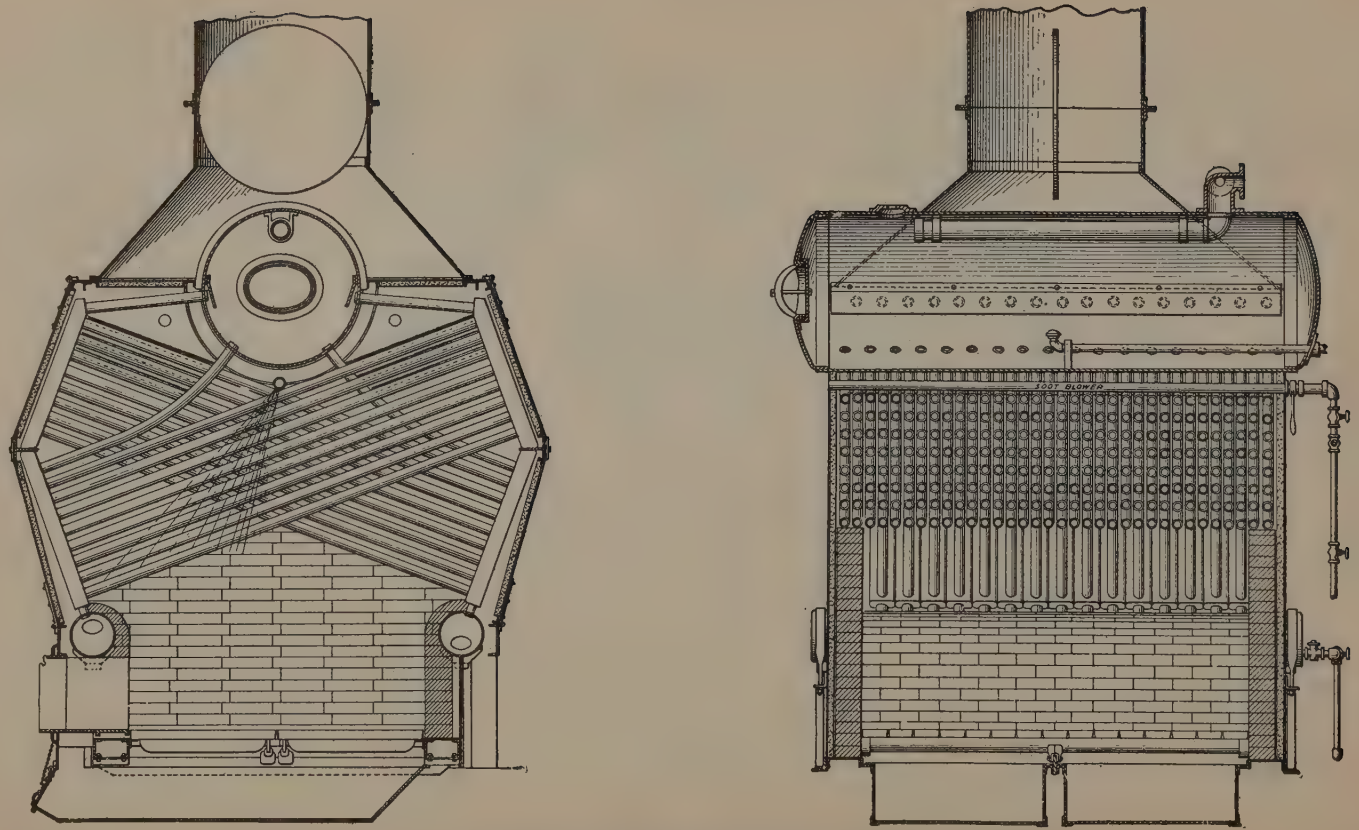


Fig. 47. Vertical Longitudinal and Cross Sections of Page-Burton Water-Tube Sectional Boiler

Courtesy of Page Boiler Company, Chicago

The hot gases from the fire pass among the tubes three times in practically the same manner as in the Babcock and Wilcox boiler.

Worthington. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Sectional.* This form of boiler is much the same in principle and operation as the Babcock and Wilcox boiler, but the parts are differently proportioned and arranged, Fig. 47. The furnace extends under the entire boiler, and the tubes are set over it close together in oppositely inclined series. No flame walls or baffle plates are used.

Construction. Boilers up to 125 h. p. are usually made to fire at the end as shown in Fig. 47, in which the tubes extend across the furnace from front to back, and the steam and water drum is at right angles to the tubes as shown in the cross section. The tubes of each vertical row are expanded into straight headers which contain seven or eight tubes. Opposite each tube is a handhole. These headers are arranged close together, forming the boiler enclosure.

Circulation. The feed water enters the steam and water drum and the circulation carries it down through pipes running to the lower headers and from thence into the mud drums as shown. From the mud drum it rises through the inclined tubes over the fire into the upper headers. The water now containing bubbles of steam enters the steam and water drum by means of short tubes shown in Fig. 47.

The covering for this boiler is an iron casing, no brick being used except to enclose or line the furnace.

Edge Moor. *Tubes Nearly Horizontal—Drums Horizontal—Straight-Tube—Non-Sectional.* The Edge Moor water-tube boiler differs from those previously discussed among the water-tube class in this respect, that the tubes, instead of being expanded into sections, are expanded into box-shaped headers which are large enough to include all of the water tubes. The tubes are always 4 inches in diameter and usually 18 feet long, though they may vary from this length.

Construction. Fig. 48 illustrates the general form of construction; this same figure shows how superheating surface is added, the latter being shown by the loops located between the drums and the tubes.

Fig. 49 shows clearly how the headers are connected with the drums in such a manner as to avoid the construction of a "throat" through which the steam and water must pass after leaving the tubes in their circulation through the boilers. This is a distinctive

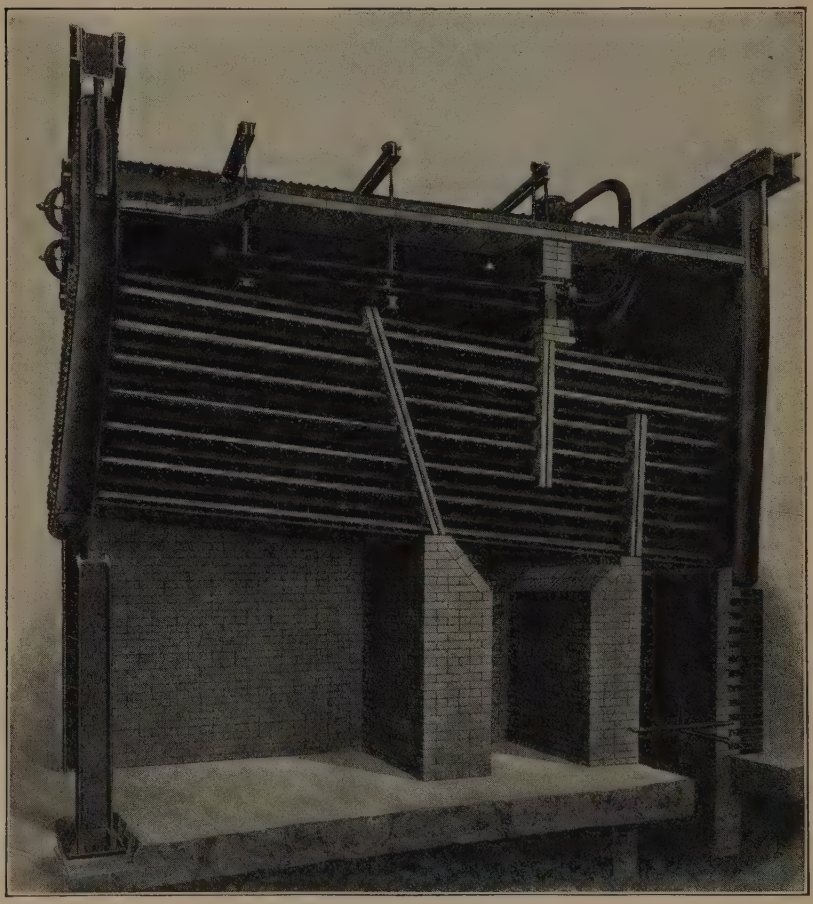


Fig. 48. Edge Moor Boiler Showing Superheaters. Boiler Construction is Standard; Setting Special

Courtesy of Edge Moor Iron Company, Edge Moor, Delaware

feature of the Edge Moor boiler. Note that the drums do not project through the headers.

Fig. 50 shows the flanged handholes opposite each tube end and the elliptical cover plate, which, on account of its shape, is inter-

changeable and, with the aid of a gasket, carries the boiler pressure so as to hold the plate to its seat. This construction is unique on account of the flanging feature and, because the metal is retained between the handhole openings, permits desirable tube spacing opposite with the assurance that there is ample strength in the handhole sheet. The stays across the header are usually solid.

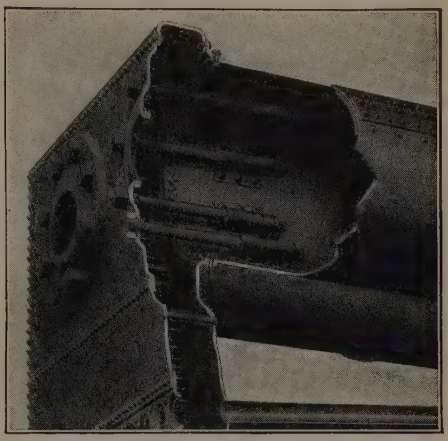


Fig. 49. Header and Drum Connections in Edge Moor Boiler

Circulation and Operation. The circulation of steam and water is identical with that previously described for the Babcock and Wilcox boiler. The aim of the construction is to provide as little internal resistance to circulation as possible by the removal of obstructions. In setting features this boiler has been installed in a great variety of ways; the normal large boiler is usually similar to that of the Babcock and Wilcox shown in Fig. 41; in special instances as shown in Fig. 48; and for the smaller sizes as shown in Fig. 52.

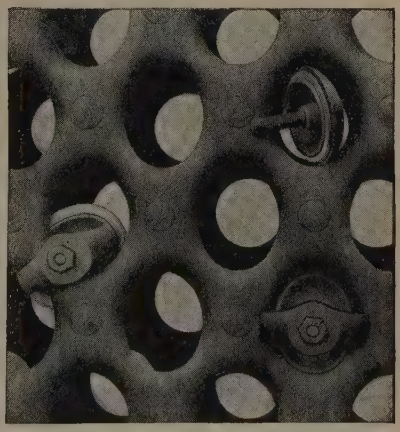


Fig. 50. Arrangement of Elliptical Flanged Handholes of Edge Moor Boiler

Heine. *Tubes Nearly Horizontal—Drums Parallel to Tubes—Straight-Tube—Non-Sectional.* The Heine water-tube boiler is not a sectional boiler. Instead of being expanded into small headers grouped to form a boiler, all the tubes, which are $3\frac{1}{2}$ inches in diameter, are expanded into the inside plates of a water leg at each end.

Construction. The construction of this water leg is shown in Fig. 51. It is composed of two parallel plates flanged and riveted

to a butt strap. The plates are strengthened by short hollow screw stays similar to those used in the water-leg construction of fire-box boilers. At the top, the water leg is curved and joined to the steam and water drum by riveting. Opposite each tube is a circular handhole for cleaning the tube, or replacing it if defective.

Circulation. The feed water enters at the front of the steam and water drum, Fig. 52, and flows into the mud drum, a small drum shown at the rear of the steam and water drum. From here it passes to the rear header with much less velocity. The water is warmed while passing through the pipe leading to the mud drum, and as it flows slowly through the mud drum it deposits its sediment. The accumulated sediment is blown off by means of the blow-off pipe at the rear. The water, as it becomes heated in the mud drum, rises and passes to the front of the mud drum, from which it flows in a thin sheet to the rear of the steam and water drum and to the rear water leg. From the rear water leg it enters the tubes, in which it is partly converted into steam. The mixture of steam and water enters the higher end of the drum from the water leg. A deflection plate prevents water from being carried to the perforated steam pipe shown at the highest point of the drum.

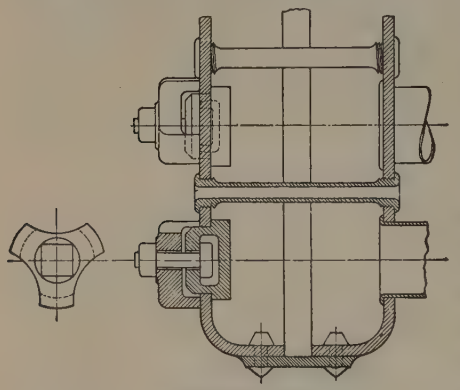


Fig. 51. Heine Boiler Water Leg

The flow of hot gases from the fire is directed by tile placed on the top and bottom rows of tubes as shown in Fig. 52. The hot gases flow nearly parallel with the tubes instead of across them as in the Babcock and Wilcox and in the Edge Moor boilers.

Mosher. *Tubes Nearly Horizontal—Drums (Cross Type) Horizontal—Bent-Tube—Non-Sectional.* The chief difference between this boiler and those already described is that it has short bent tubes, thus making a more compact boiler. This type is more often used in marine than in stationary work. The boiler consists of a large steam and water drum, Fig. 53, connected by slightly curved

tubes to a smaller water drum. The steam drum is supported by two large circulating pipes, one at each end, which are connected by other pipes to the water drum. Thus the circulation is down these pipes and along the pipe at the bottom up to the water drum, and thence to the steam drum by the tubes which are in contact with the hot gases.

The feed-water heater, or economizer, shown above the main drum, consists of two small drums connected by tubes. The paral-

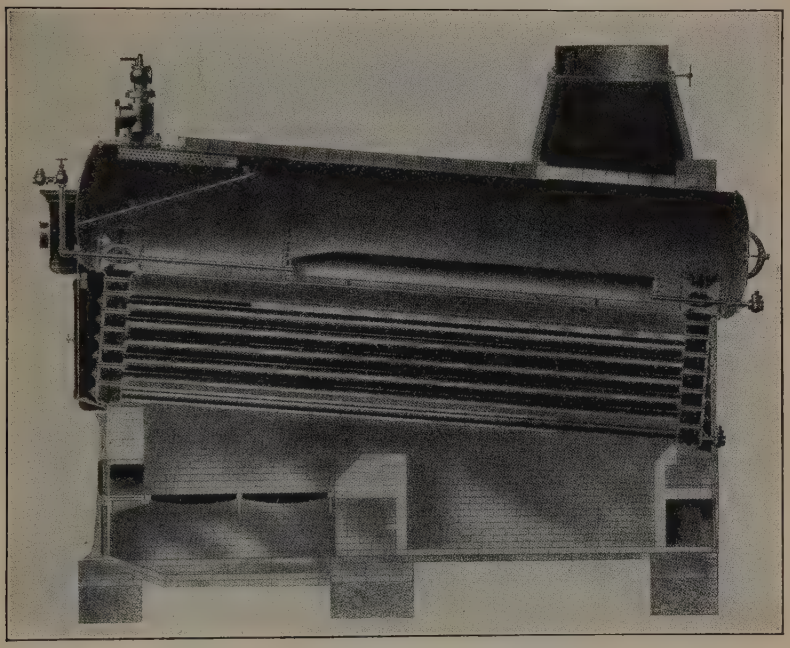


Fig. 52. Longitudinal Section of Heine Water-Tube Boiler and Setting
Courtesy of Heine Safety Boiler Company, St. Louis, Missouri

lel dotted lines in the steam drum show how tubes are removed and replaced, a series of openings, which are capped with plugs as shown in Fig. 54, being provided in the upper drum for removing the tubes. All the tubes in one vertical section pass through one opening. Each plug is a conical-headed bolt, having a short piece of copper tube, a washer, and a nut. The conical head and the copper tube are inserted in the hole until the washer is in contact with the outer surface of the drum. The nut is then screwed up, thereby flaring the end of the copper tubing as shown. The

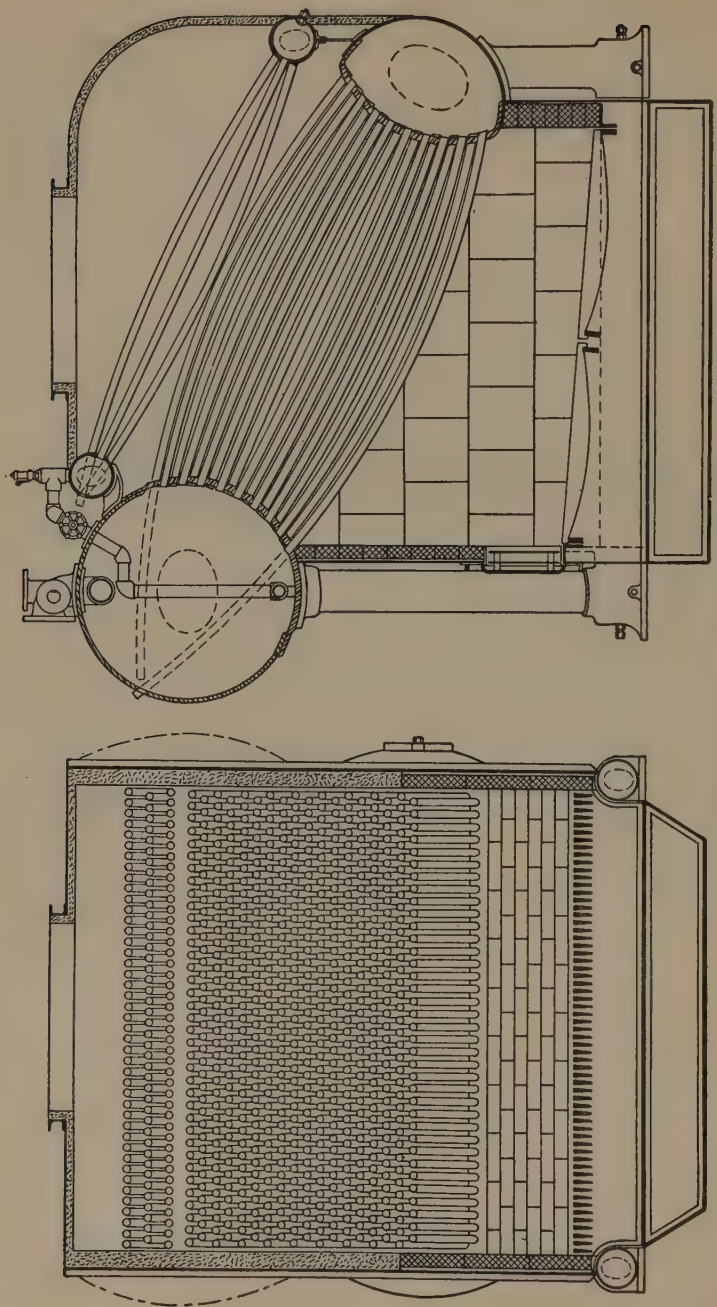


Fig. 53. Cross and Longitudinal Sections of Mosher Boiler, Showing Details of Boiler and Setting

steam pressure on the conical head increases the tightness of the joint.

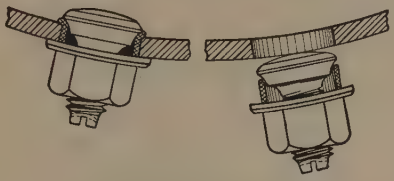


Fig. 54. Mosher Drum Plugs

Thornycroft-Marshall. *Tubes Nearly Horizontal—Drums (Cross Type) Horizontal—Bent-Tube—Non-Sectional.* The Thornycroft-Marshall non-sectional boiler consists of a large horizontal steam and water drum, a vertical water box or header, and the generating tubes. Like the Mosher, the tubes are bent slightly, but the header is quite different from that boiler.

Construction. The general features of construction are shown in Fig. 55. The steam and water drum, sometimes called the separator barrel, is simply a cylinder with dished ends. The water is carried at about one-third the height of the cylinder. The tubes, which are $3\frac{1}{4}$ inches in diameter, are connected in pairs to a junction box at one end and to a water box or header at the other end. Thus each pair forms a unit, but the two tubes of the unit are not in the same vertical plane. The upper tube enters the header as high as possible and the lower ones enter low down, thus giving considerable upward slope. From near the top of the water box, three rows of tubes lead to the separator barrel as shown in Fig. 56. The water box is simple in construction, the flat plates being stayed by short hollow screw stay bolts. The junction boxes are not restrained in any way; this construction, combined with the slight curve of the tubes, allows free expansion.

Circulation. The feed water enters the steam and water drum and then passes to the water box through the two lower sets of tubes, Fig. 55. The water enters the lower ends of the various pairs of tubes, as shown in Fig. 56, and rises in the tubes while in contact with the hot gases from the furnace. The mixture of steam and hot water then enters the header, from which it passes to the steam and water drum by means of the highest row of

tubes. The difference in height of the two tubes of a unit insures good circulation. A baffle plate prevents the water from splashing to the steam pipe.

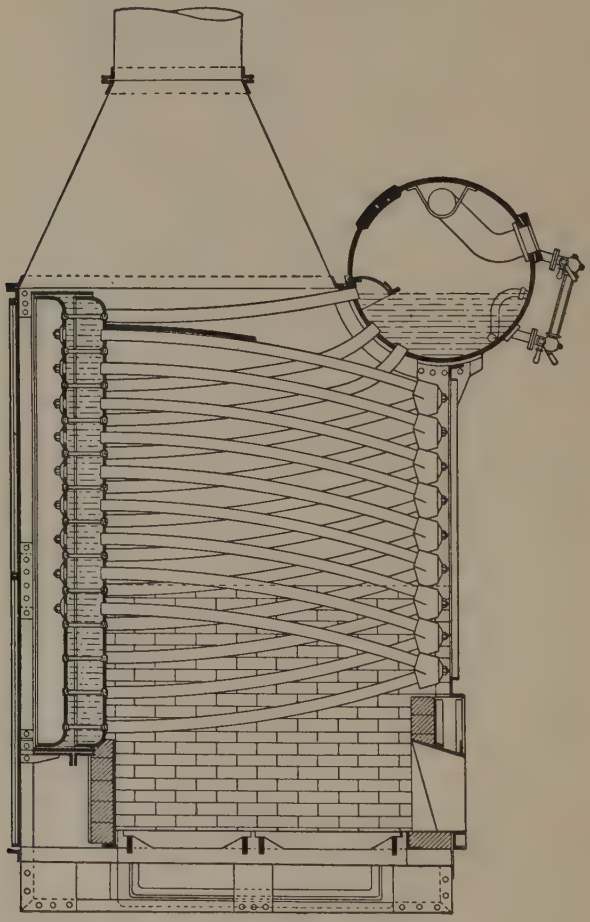


Fig. 55. Vertical Section of Thornycroft-Marshall Boiler

The hot gases pass upward among the tubes which cross so frequently that the heating surface is quite efficient.

Niclausse. *Tubes Nearly Horizontal—Drum Horizontal—Straight-Tube—Sectional.* This boiler differs essentially from those already described in that it is of the double-tube type. In general,

it consists of a number of elements which form a vertical header, to which tubes are connected. The tubes are set at an angle of about 6 degrees to the horizontal. Above the elements is a transverse steam and water drum which is in communication with the headers. The general arrangement of parts is shown in Fig. 57.

Construction. The interesting feature of this type of boiler is the arrangement of the tubes and headers. To increase the circulation the principle of the "Field" tube is employed. In this construction the outer or generating tubes, $3\frac{1}{4}$ inches in diameter, are closed at one end. Each generating tube contains an inner

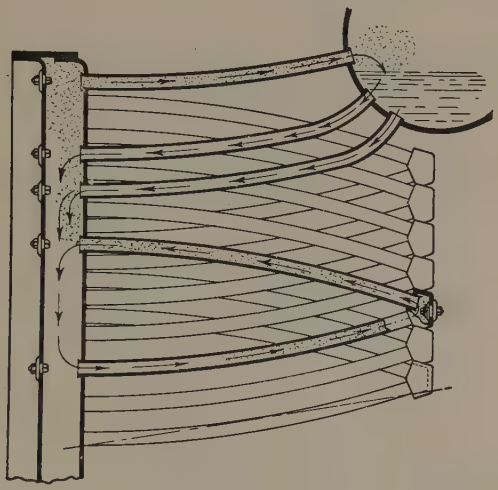


Fig. 56. Diagram Showing Circulation in Thornycroft-Marshall Boiler

circulating tube which is $1\frac{19}{32}$ inches in diameter, open at both ends. The closed ends of the generating tubes are supported by being placed in holes in a plate or rack at the rear of the boiler. The forward end of the circulating tube is attached to a cap which screws into the outer end of the generating tube. A recess in this cap provides a bearing for an arch bar which spans two tubes, keeps them in place, and is itself secured by a nut on a bolt which, in turn, is screwed into the header, Fig. 58.

The front end of the generating tubes is of peculiar shape. To allow the water to enter the circulating tubes, and to fasten the tubes to the header without expanding them, each generating tube

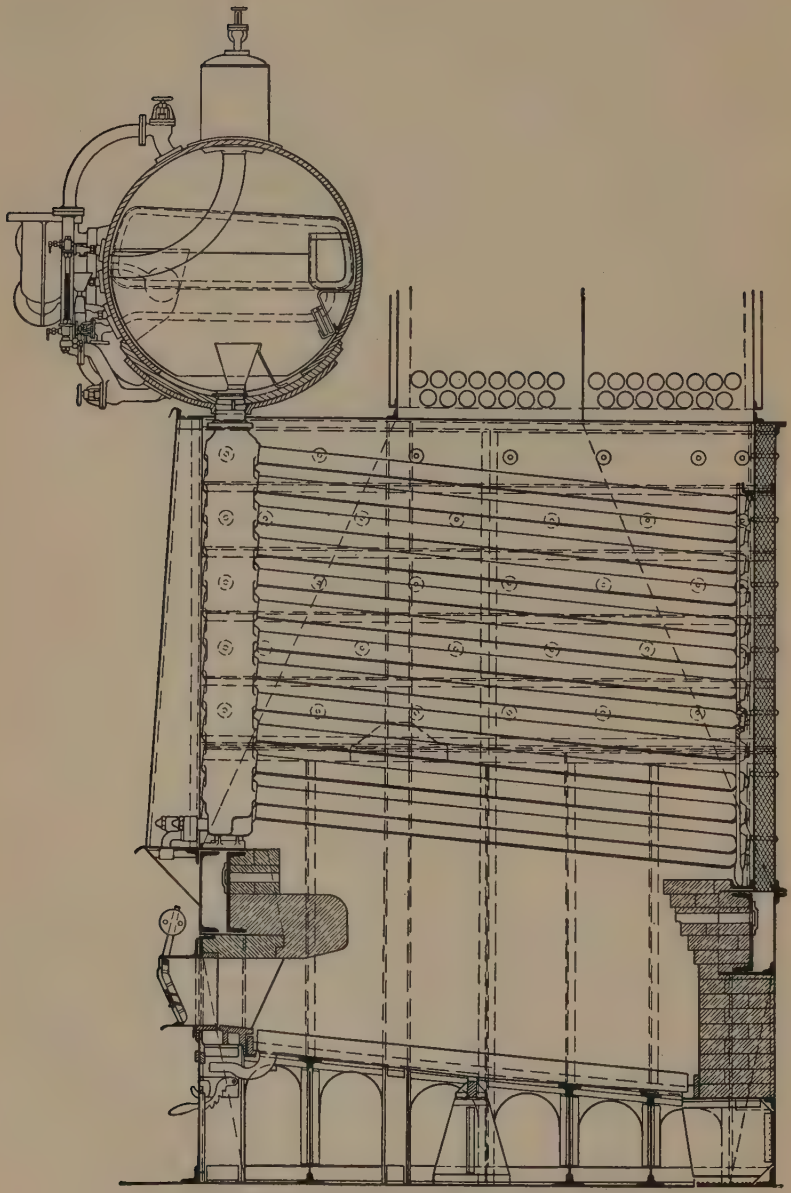


Fig. 57. Vertical Section of Niclausse Water-Tube Boiler

is provided at the open end with two cone-shaped parts; these are about 8 inches apart. The first cone fits into a taper hole flanged outward in the front face of the header, and the second cone fits a similar hole in the rear face of the header. Both the holes and tubes are ground to the same size and taper. About midway between the cones, a third expanded portion occupies the tube hole in the diaphragm or middle plate of the header, Fig. 58. The portion of the tube within the header is called the "lantern". At this point the tube is cut away so that water may freely enter the tube, the openings being above and below. In Fig. 58, the upper tube is in its normal position, but the lower tube has been turned through 90 degrees to show the construction.

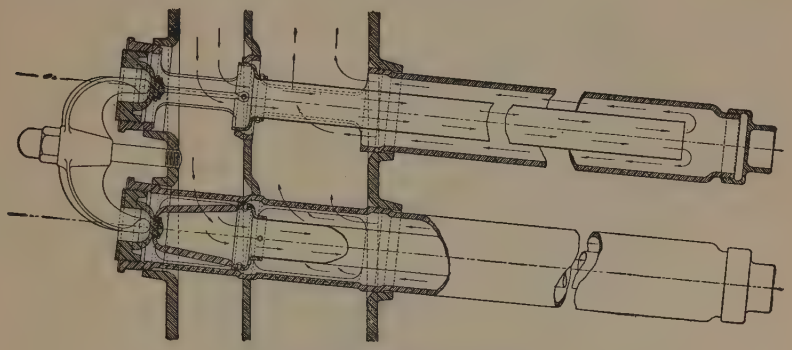


Fig. 58. Niclausse Boiler Details

To stand high steam pressures, the elements of the headers are made of wrought steel and are sinuous in shape. Fig. 59 shows the shape of the header and the positions of the tubes. Each element contains 24 tubes in two vertical rows of 12 each. In the middle of the headers, there is a diaphragm for dividing the interior. The front passage serves as a "downcomer" for the water, and the rear is the "upcomer", or riser, for the mixture of steam and water.

The lower ends of the headers are closed, and the upper ends flanged to connect with the steam and water drum, which is 42 inches in diameter.

Circulation. Fig. 58 gives an idea of the direction of circulation. Water from the drum descends in the front compartment of the header, flows into the circulating tubes, which communicate

with the front compartment only, and, after flowing the length of the circulating tubes, enters the generating tubes. The water then comes back through the annular spaces in the generating tubes to the rear compartment of the header, because the generating tubes communicate with the rear compartment only, while in the annular space it is partly evaporated. The mixture of steam and water then rises to the drum.

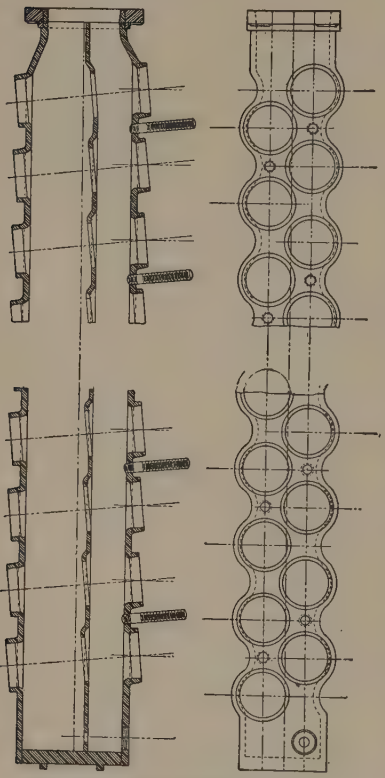


Fig. 59. Niclausse Header Details

VERTICAL TYPES

Wickes. *Water Tubes Vertical — Straight-Tube — Non-Sectional.* Let us now consider a water-tube boiler having vertical tubes. Fig. 60 shows the general arrangement of the parts of the Wickes vertical water-tube boiler. At the top is a cylindrical steam and water drum into which the upper ends of the vertical tubes are expanded. At the bottom is a cylindrical drum of the same diameter as the upper drum. The tubes are straight and plumb when in position; they are arranged in parallel rows with a clear space between rows to admit a small hoe to remove any soot that may accumulate on the tube sheet of the lower drum.

The tubes are divided into two compartments by heavy firebrick tile. The tubes in the section adjacent to the furnace are called "risers"; those in the rear are the "downcomers", because the heated water rises to the steam drum through the front tubes, and the cooler water flows down those in the rear. The feed water is introduced into the upper drum. The direction of flow of hot gases is the same as that of the water.

The furnace is extended in front of the boiler setting and built

entirely of brick. The hot gases from the fire come in contact with the tubes without passing through a combustion chamber, unless special furnace construction is adopted.

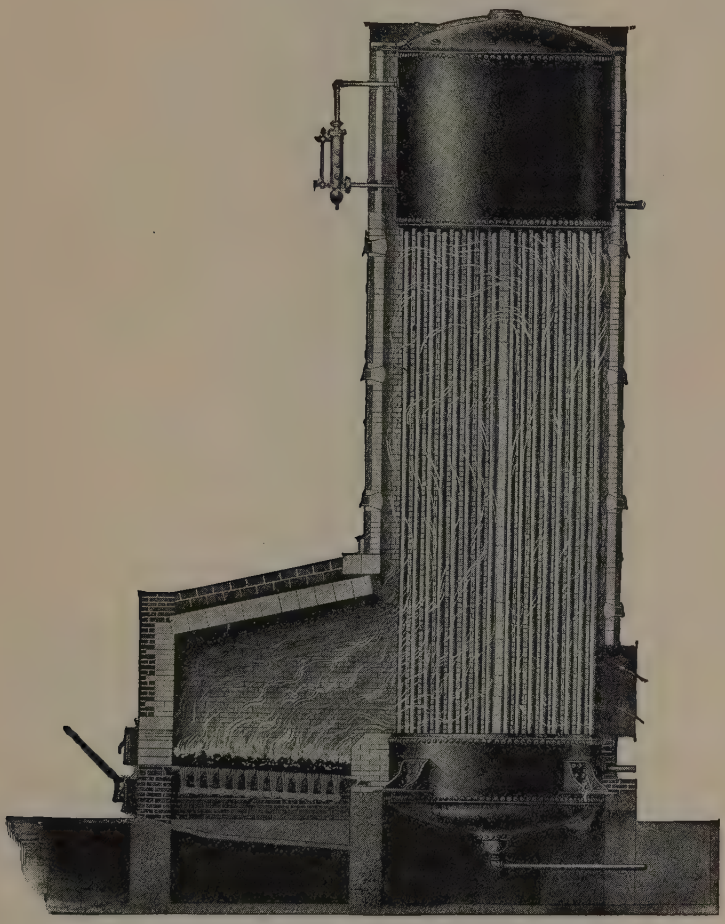


Fig. 60. Section of Wickes Vertical Water-Tube Boiler
Courtesy of Wickes Boiler Company, Saginaw, Michigan

Cahall. *Annular Steam and Water Drum—Tubes Vertical—Straight-Tube—Single-Tube—Non-Sectional.* The Cahall vertical water-tube boiler consists of an annular steam and water drum, a cylindrical lower drum, and 4-inch vertical tubes connecting these two drums. An external circulating pipe also connects the two

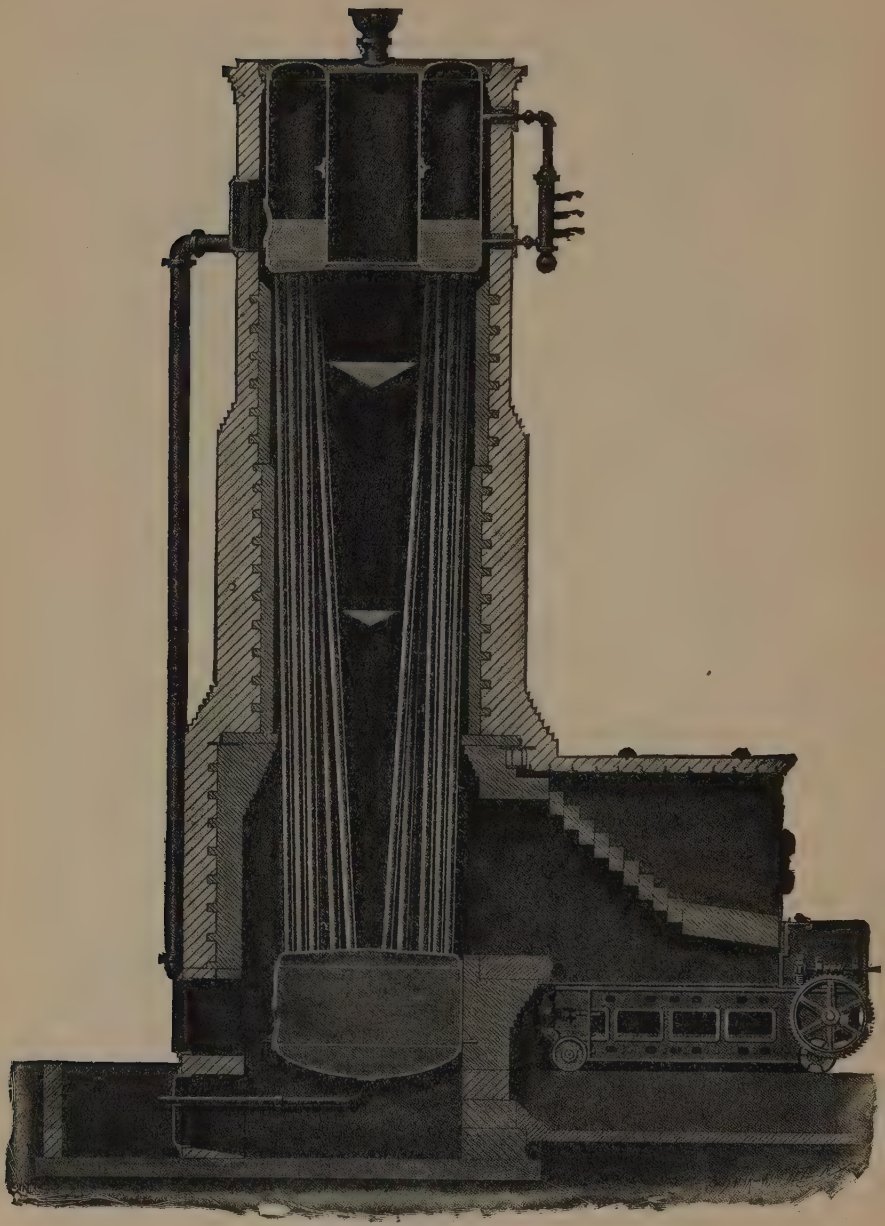


Fig. 81. Cahall Vertical Water-Tube Boiler, Showing Longitudinal Section of Setting Enclosing a Traveling Grate

drums. As this pipe is filled with comparatively cool water and the generating tubes with a mixture of hot water and steam, the circulation is up in the 4-inch tubes and down in the external pipe. The feed water enters the steam and water drum, flows down the external pipe to the lower drum, and then rises in the generating tubes to the steam and water drum.

The fire is in a brick furnace in front of the boiler, as shown in Fig. 61, the hot gases rising among the tubes. The annular form of the steam drum makes the central space conical; in this space several deflecting plates, or baffles, cause the hot gases to remain among the tubes. After heating the water in the tubes, the hot gases pass through the opening in the steam and water drum, coming in contact with the metal containing the steam. This thoroughly dries the steam and in many cases slightly superheats it.

Both the steam drum and the lower drum are equipped with swinging manheads. The steam drum also has several handholes for use in removing and replacing tubes.

Stirling. *Tubes Nearly Vertical—Drums Horizontal—Bent-Tube—Non-Sectional.* The Stirling boiler, shown in Fig. 62, consists of three cylindrical steam and water drums at the top and a mud drum at the bottom. The lower drum is connected to the upper drums by three sets of tubes which are curved slightly at the ends. The curved tubes allow for expansion and make it possible to have the tubes enter the drums radially.

The feed water enters the rear steam and water drum and, coming in contact with the hot gases just before they enter the uptake, becomes gradually warmed. This heating causes most of the sediment to fall to the mud drum, from which it may be blown out at intervals. The mud drum is protected from the intense heat of the furnace by the bridge wall.

Each set of tubes is separated from the others by partition walls or baffles of fire-brick tile, so that the gases from the furnace pass along the entire length among the first set of tubes; they are then guided downward among the second set of tubes, and, after rising again among the tubes of the third set, escape to the chimney. The fire-brick arch just above the furnace insures an even distribution of the gases and promotes combustion; the arch heats the

entering air to a high temperature, thus reducing the danger of chilling the tubes by an inrush of cold air.

Steam is taken from the middle drum, which is set a little

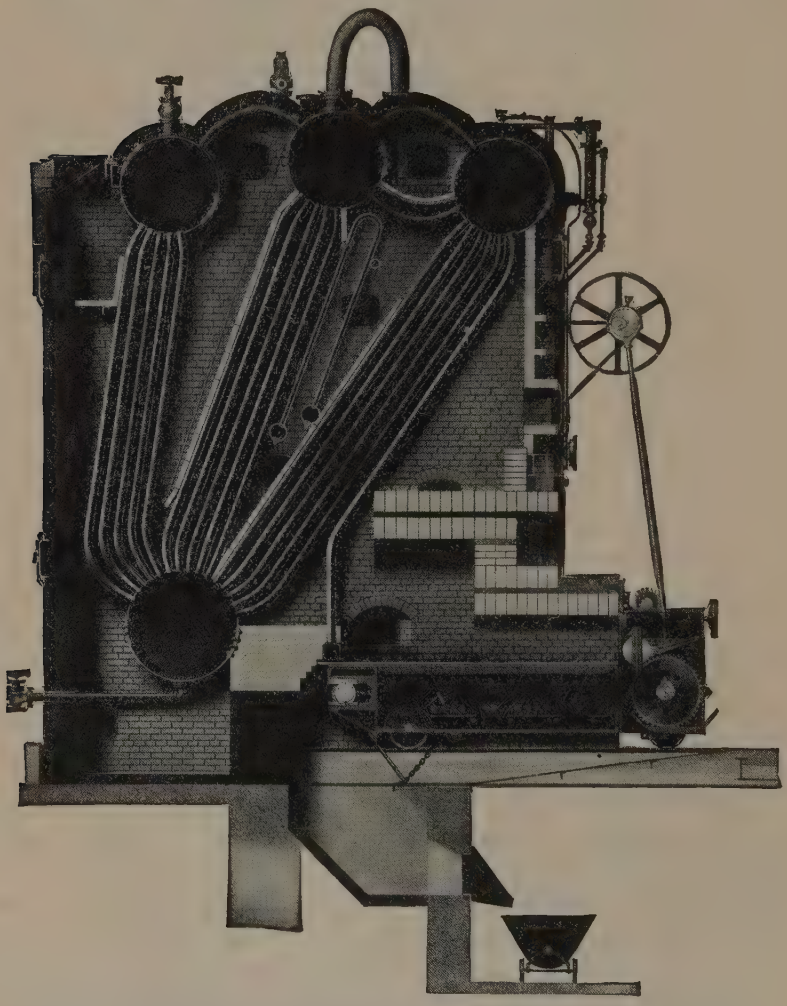


Fig. 62. Longitudinal Section of Stirling Boiler, Showing Setting and Mechanical Stoker
Courtesy of Babcock and Wilcox Company, New York City

higher than the others in order to obtain more steam space. The boiler is surrounded on the rear and two sides by the brick setting; the front is of cast iron or of pressed steel. Numerous openings in the brickwork allow entrance for cleaning.

This type of boiler is flexible and adapted to cramped places, as it can be made broad with little height or high with small floor area. All parts are either cylindrical or spherical in shape and of wrought metal. The curved tubes reduce the strains resulting from unequal expansion and contraction.

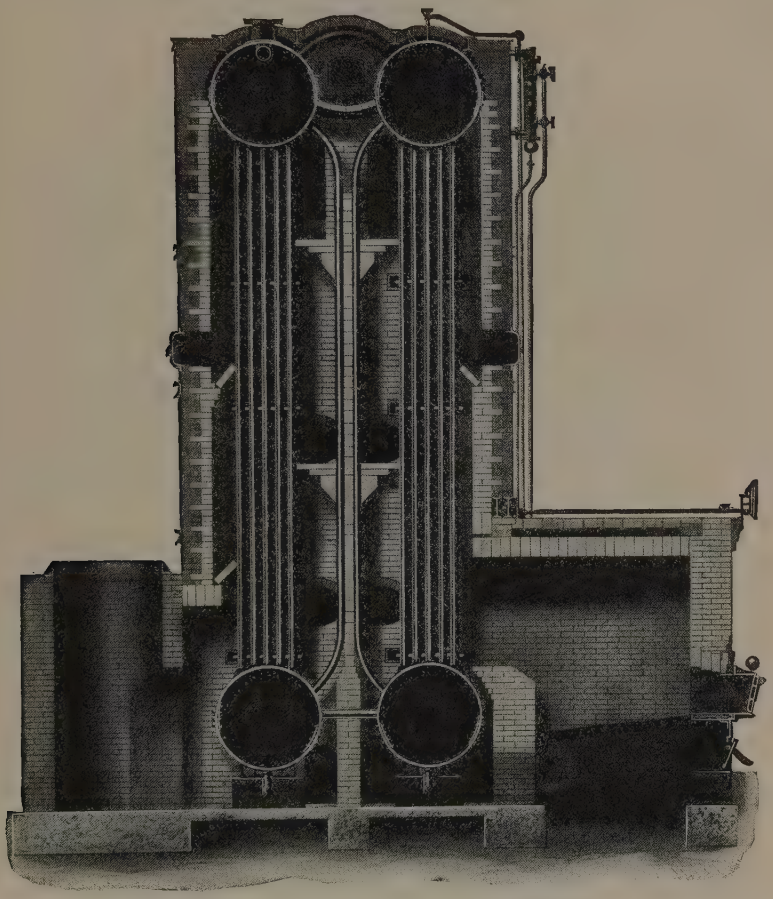


Fig. 63. Vertical Section of Rust Water-Tube Boiler
Courtesy of Babcock and Wilcox Company, New York City

Rust. The Rust water-tube boiler, manufactured by the Babcock and Wilcox Company, is intended to include the advantages of boilers made up of drums and tubes only, thus getting away from the disadvantages of header construction and many handholes, and at the same time avoiding the use of bent tubes. To accomplish

this the vertical boiler illustrated in Fig. 63 is made up of straight tubes and four drums, with the exception of two rows of vertical tubes and the circulating tubes connecting the two upper drums, which are bent. The purpose of the two rows of bent tubes in the middle section is to provide a stable support for the baffle wall. When superheaters are used they are located with the elements projecting almost up to the top rear drum, close to the middle baffle wall in the space between the bent tubes and the straight tubes.

Fig. 64. Section Showing How Rust Boiler Tubes are Set into Drum

In order that the tubes may be inserted into their holes normal to the surface of the drums, the drum sheets are forged hot in a hydraulic press fitted with special dies, the effect of this forging being shown in Fig. 64.

Bigelow-Hornsby. The development of the Bigelow-Hornsby boiler is an attempt to satisfy the demand for large boiler capacity without resorting to the double- and triple-deck boiler-house design. A section consists of four tube units suspended from structural iron overhead and connected by short tubes to a central steam drum as shown in Fig. 65. As the main steam drum is the only rigid member, expansion and contraction are easily taken care of, no matter how many sections are used or how long the central drum is made. The boilers rate at 125 horsepower per section, so that a boiler of 1250 horsepower has ten sections. The water circulation is down the rear units and up the front as well as in the individual units themselves. The feed water enters the top rear unit drums and mixes with the downward circulating currents, thus providing that the coldest water shall meet the coldest gases. On account of the open structure of the boiler, it is an easy matter to inspect and clean it. As the tubes are perfectly straight, one can look through them and see if they need cleaning. The baffle-plate arrangement is shown in Fig. 65, the tile being placed at the back of each unit between the successive sections, thus making the hot gases pass through the tubes of the forward unit to the second and so on. When used, a superheater is placed below the main steam drum. This boiler is developed from the Hornsby, an English type.

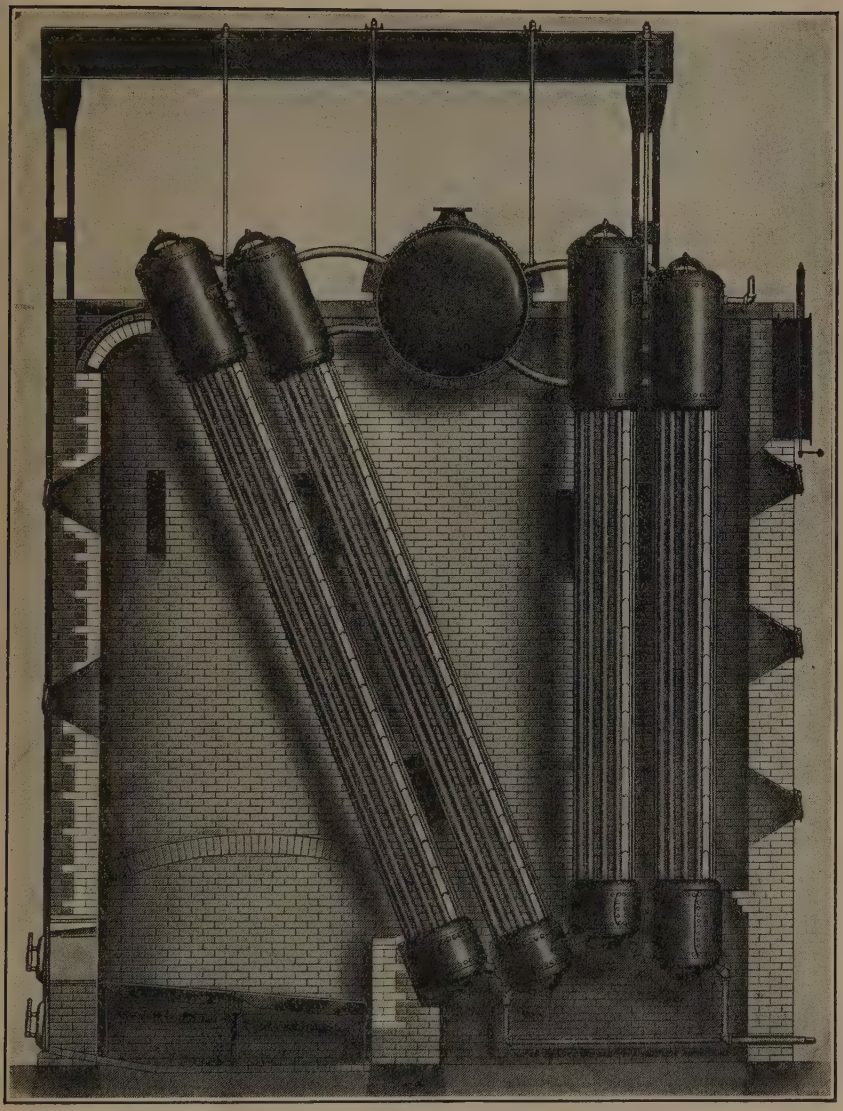


Fig. 65. Section of Hand-Fired Bigelow-Hornsby Vertical Boiler
Courtesy of The Bigelow Company, New York City

Connelly. *Tubes at Various Pitches—Drums Horizontal—Bent-Tube—Single-Tube—Non-Sectional.* The Connelly boiler, shown in Fig. 66, consists normally of two cylindrical steam and water drums and one water drum at the top, all three of which connect with a mud drum at the bottom. When the units are built especially large, this boiler may consist of as many as seven

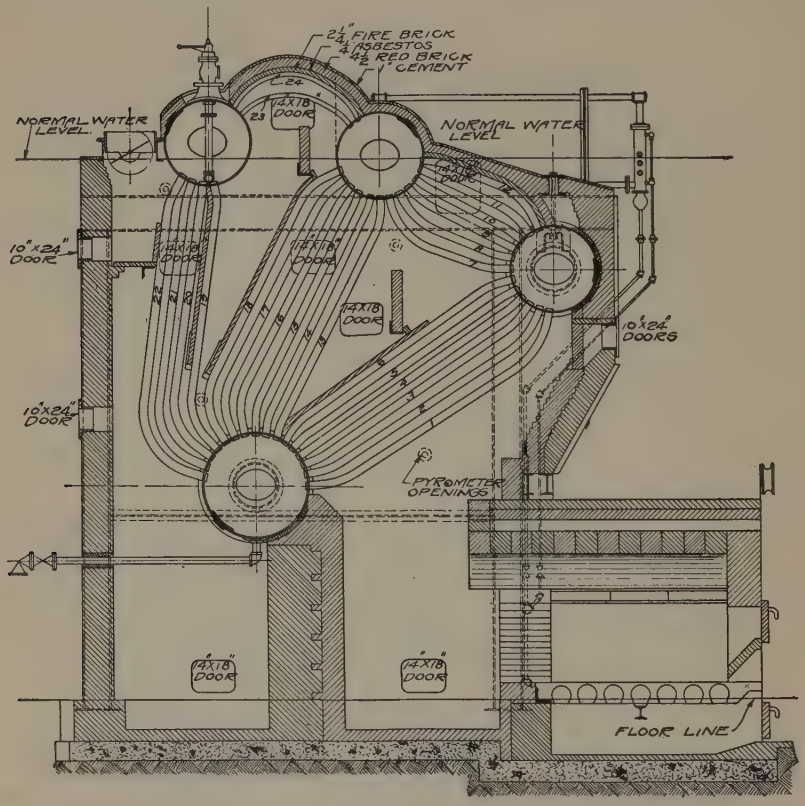


Fig. 66. Connelly Water-Tube Boiler
Courtesy of D. Connelly Boiler Company, Cleveland, Ohio

drums arranged by uniting two boilers of the four-drum type into one pressure unit, the place of articulation being the front top water drum of each, thereby permitting the rejection of one of these drums. In any of the boilers of this general design all the tubes are bent to the required shapes so as to enter the drums radially.

Circulation. The feed water enters the rear top drum, which is also the place from which steam is taken. Normal water circulation carries the new water from the rear top drum down to the mud drum, from which it rises to either the top front or middle drum. Steam separation occurs in the middle top drum, from which it passes by means of bent connecting tubes to the rear top drum.

The spacing is such as to permit the removal of any tube without disturbing the rest. While the boiler is baffled in several different ways, the standard form is shown in the illustration. Particular attention is called to the facilities provided for admitting a portion of the traveling hot gases to the chamber formed by the circulating tubes leading from the middle drum to the rear drum. The expectation is that heat will be delivered to the steam, causing it to be slightly superheated. It is suggested that this boiler be studied in comparison with the Stirling boiler illustrated in Fig. 62.

Erie City. *Tubes Vertical—Drums Horizontal—Bent-Tube—Non-Sectional.* The Erie City vertical water-tube boiler, illustrated in Fig. 67, consists of one upper steam and water drum communicating by means of bent tubes to a bottom mud drum. In ordinary sizes, the tubes are arranged in three banks—four rows in the front two banks and three rows in the rear bank.

Circulation. The water is fed in the center of the lower mud drum, rising in the front banks of tubes to the top drum, where entrained steam bubbles are separated. The cylindrical shell of the top drum is longer than that of the mud drum, the additional length being devoted to two internal steam compartments over which the ends of the dry pipe project so as to remove, as far as possible, the steam outlet of the boiler from the places of most violent ebullition.

Two baffles are constructed to cause the gases to follow the heating surface. The first baffle is built from the lower drum to within a few feet of the top drum, leaning upon the back row of tubes of the first bank. The second baffle extends from the upper drum to within a short distance of the lower drum. This arrangement combined with the setting walls compels the hot gases to

traverse the heating surface in three passages, the outlet being at the top rear of the setting.

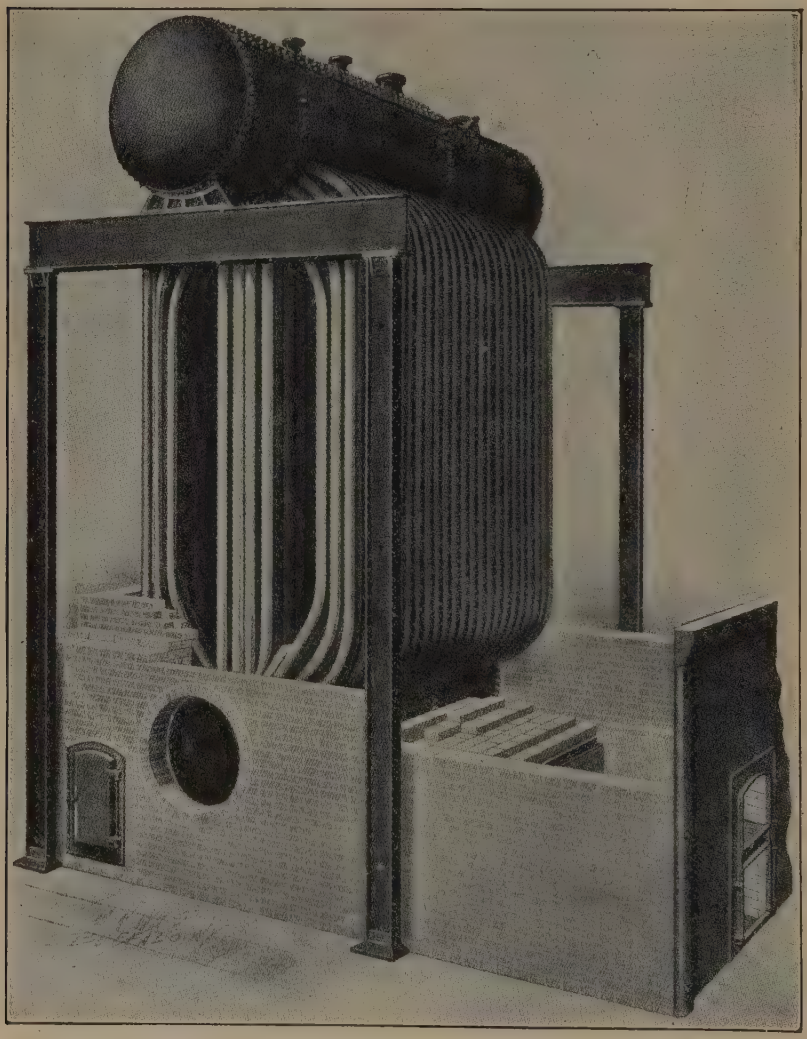


Fig. 67. Erie City Vertical Water-Tube Boiler. Brick Setting Incomplete, Baffles not Inserted

Courtesy of Erie City Iron Works, Erie, Pennsylvania

The tubes are independently removable, the spacing being so arranged. Also they are bent in such a form as to enter the drums radially.

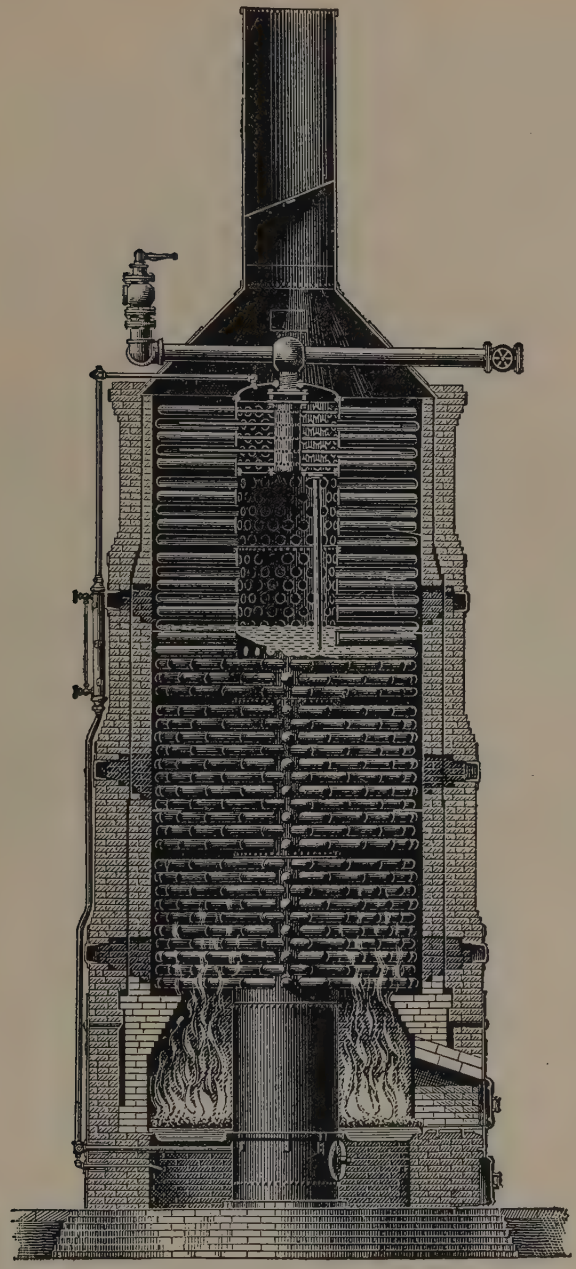


Fig. 68. Vertical Section of Hazelton Porcupine Boiler and Setting

PECULIAR FORMS

Hazelton or Porcupine. *Tubes Horizontal—Drum Vertical—Straight-Tube.* The Hazelton water-tube boiler differs in many respects from the boilers thus far described. Like most water-tube boilers it consists of a steam and water drum and water tubes, but the central standpipe is vertical and the short horizontal tubes radiate from the central drum. According to our classification it is not a vertical water-tube boiler because the tubes are horizontal; also, it is not a horizontal boiler, as in general appearance it is vertical.

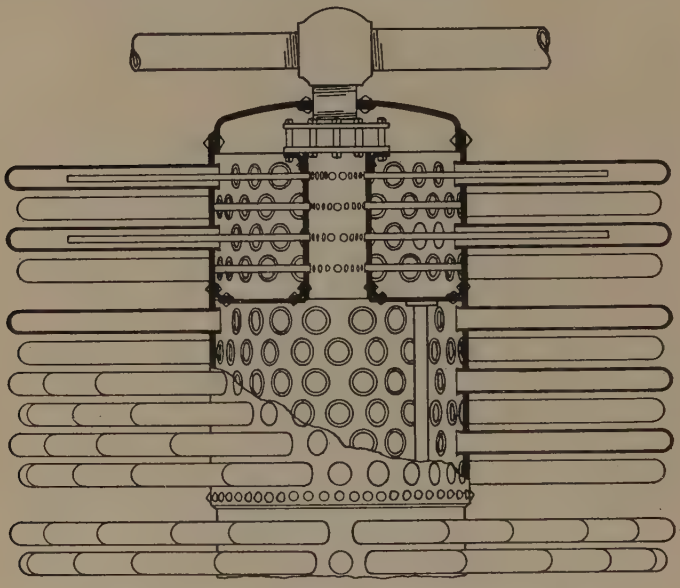


Fig. 69. Part Section of Porcupine Boiler Showing Center Tubes

The grate is circular and formed around the central drum, which rests on a circular cast-iron foundation. Above the grate, the central drum forms part of the heating surface and is the steam reservoir; below the grate it is the mud drum, which may be entered by means of a manhole just below the grate. As shown in Fig. 68, the standpipe above the fire is provided with radial tubes. The arrangement of these tubes gives the boiler the name "Porcupine".

The standpipe is about 3 feet in diameter for large boilers. The tubes are about 4 inches in diameter, and project out from the

standpipe about $2\frac{1}{2}$ feet, the number varying with the size of the boiler. The outer ends of the tubes are closed and hemispherical, and the inner ends expanded into the standpipe. The tubes are free to expand and contract without bringing any stress on the boiler.

Steam is taken from the top of the central drum. To get dry steam, small pipes are inserted as shown in Fig. 69. The steam passes up into the small tube at the top of the standpipe and then through the small pipes to the ends of the generating tubes. It

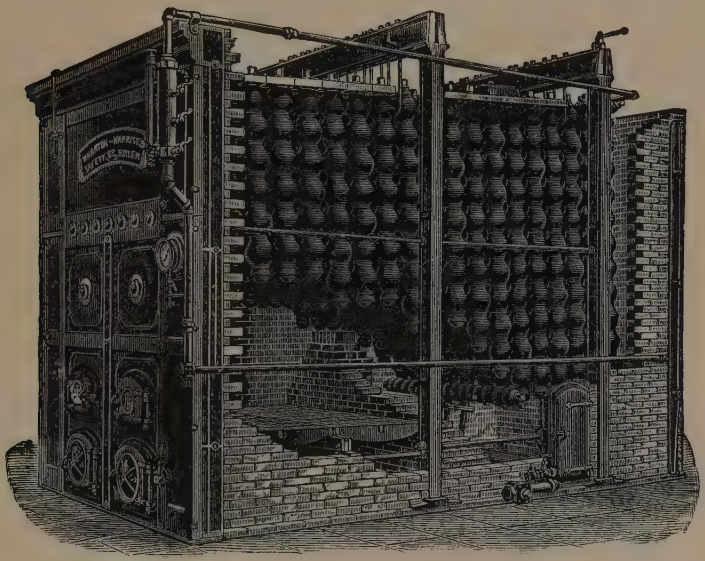


Fig. 70. Harrison Safety Boiler. A Type no Longer Manufactured but Still Used
Courtesy Harrison Safety Boiler Works, Philadelphia

then flows back through the generating tubes to the annular space, and thence to the steam pipe. The feed pipe enters the mud drum and extends upward nearly to the water line; it then returns nearly to the level of the grate, terminating in a spraying nozzle.

This type of boiler may be enclosed in a brick setting, as shown in Fig. 68, or by a sheet-steel covering lined with fire brick.

Harrison. *Sectional—Hollow Cast-Iron Spheres Instead of Tubes.* All boilers thus far described have employed tubes as a means of dividing the water into small masses in order to make the heating surfaces more effective. In the Harrison safety boiler, Fig.

70, tubes are not used; instead, the water is contained in hollow cast-iron spheres, called units. These units, Fig. 71, are arranged in vertical rows, called slabs, which are suspended side by side, about one inch apart, from an iron framework. The brickwork setting is merely a covering to keep the hot gases in contact with the units.

The use of units in place of tubes combines great strength and a large heating surface. They are strong because small and spherical, and, on account of the division of the water into small masses, the heating surface is effective. The units are held together by long bolts which pass through the centers, as shown in Fig. 71. The machined faces make a steam-tight joint without packing. This boiler requires the same fittings as other boilers

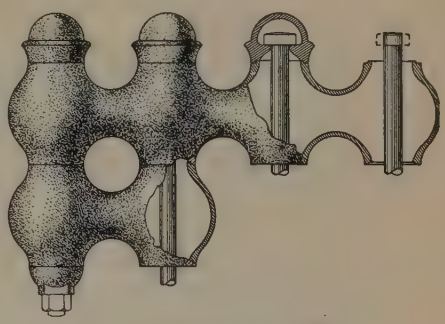


Fig. 71. Details of Harrison Boiler Units

The great advantage of this boiler is safety. From the construction, it is apparent that rupture cannot extend beyond the unit; thus disastrous explosions cannot occur. They are claimed to be durable, economical, rapid steamers, and easily handled. The capacity can be increased by merely adding more slabs.

MARINE BOILER TYPES

Elements of Design. Because boilers used in marine work must be built to meet the special conditions imposed by the construction of the ships containing them, and because boiler practice is slightly different at sea than on land, it is thought best to point out the main features of design encountered in marine boilers, grouping them together in one part of this article so as to distinguish them as a class, even though all of them must classify among the different groups according to form, as, for instance, "fire-tube", "water-tube", etc. The principles governing the construction of marine boilers cannot be different from those governing the construction of all other boilers, and whatever differences are shown

come from the restrictions imposed by the spaces into which the boilers must go, and because of the attempt to reduce fire hazard.

Marine boilers usually take one of the following forms:

(1) Rectangular, or box boilers
(2) Cylindrical, or drum boilers
(3) Water-tube boilers

As was pointed out with respect to boilers used in stationary plants, the tendency is toward the greater use of water-tube boilers on account of their greater safety under high pressures, and because they are somewhat more compact for a given horsepower. It will be seen, also, that the internally-fired type of boiler, which at one time supplanted nearly every other form of marine boiler, presents the difficulty of offering very limited facilities in the matter of grate surface; and this one fact has contributed not a little to the adoption of water-tube boilers in their stead. From these remarks it must not be inferred that cylindrical boilers are not now frequently used in marine work; they are still the most common boilers on board ship, but the newer vessels, and especially the larger ones, are being equipped with water-tube boilers built particularly for marine use.

RECTANGULAR MARINE FIRE-TUBE BOILERS

Features of Construction. The rectangular boiler, Fig. 72, is made square or box-shaped; hence the sides are flat. This form was one of the earliest used; at present, however, its use is restricted to low pressure, that is, under 30 pounds per square inch. The reason why this boiler cannot be used for high pressure is because the flat plates tend to bulge outward when under high pressure. In order to prevent the plates from bulging, they must be stayed with numerous longitudinal and vertical stay rods.

Box boilers are generally made with an internal uptake, as shown in Fig. 72. This construction makes possible a larger steam space and reduces loss of heat by radiation. It is, however, expensive in first cost and repairs; also, the plates of the uptake waste rapidly, especially near the water line, because the heat is not transmitted as readily by steam as by water. In case the uptake is made separate and does not form a part of the boiler, this objection is avoided.

The tubes of the rectangular boiler are usually horizontal, or nearly so. When set inclined or with a "rake", as it is called, there is more room for manholes at the smoke-box end. The extremities of the tubes at the combustion chamber end are near the furnace, but are higher at the smoke-box end. The water level is about the same as with the horizontal tubes, the ends nearest the combustion chamber having the greater depth of water over them. The inclination is about 1 inch to the foot.

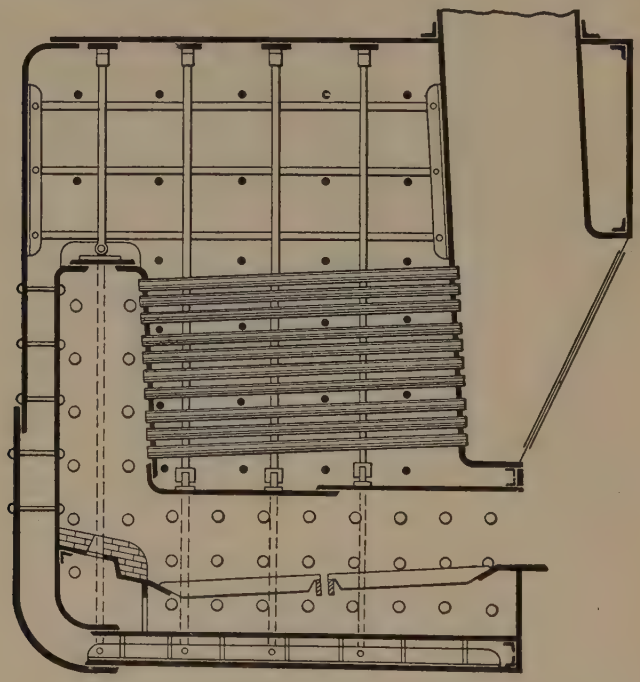


Fig. 72. Wet-Bottom Rectangular Marine Boiler

Wet- and Dry-Bottom Boilers. Rectangular boilers are made in two ways, and from the form of construction are known as "wet bottom" and "dry bottom". Wet-bottom boilers are made with the furnace wholly inside and independent of the shell, the furnaces being surrounded by water on all sides. The wet-bottom boiler is very difficult to inspect and repair.

In the dry-bottom boiler, the furnaces terminate in the boiler shell at the bottom, having a water space called the water leg

between them. This water leg causes trouble by getting filled up with sediment. The furnace has water around the sides but, like the locomotive and most vertical boilers, there is no water underneath. The dry-bottom boiler is lighter, as the bottom plates are omitted, is cheaper, has greater durablity, and is easier to examine. On the other hand, it is more dangerous to the ship, as the heat is likely to cause corrosion of the frames if of iron or burn the frames if of wood.

In order to avoid the large number of stays in the steam space for pressures over 30 pounds per square inch, an oval-shaped boiler was introduced. It had a semicylindrical top and bottom and flat sides. This form was soon abandoned because it would stand only about 45 pounds pressure.

CYLINDRICAL MARINE FIRE-TUBE BOILERS

The cylindrical boiler succeeded the oval boiler. This boiler is made with the shell a complete cylinder. It is lighter, cheaper, and more easily made than the rectangular. It occupies more space and for a given heating and grate surface, has a smaller steam space. Cylindrical or Scotch boilers may be divided into three classes, as follows:

(1) Single-ended boilers
(2) Double-ended boilers
(3) Gunboat or through-tube boilers

For a detailed description of single-ended cylindrical boilers of the single-flue type see pages 23 and 24 and Fig. 21. Multiple-flue boilers are described on page 25 and shown by Figs. 22 and 23. Double-ended boilers are described on pages 25 and 27, and an excellent illustration of a multiple-flue boiler of this type is given by Fig. 24. Through-tube boilers are described on page 29 and illustrated by Fig. 27.

Locomotive Boiler. The locomotive boiler is used for launches and torpedo boats. It is a convenient form and a very light boiler for the heating surface. Forced draft is almost invariably used with it on account of the small grate area. The furnace crown, being flat, requires careful staying.

MARINE WATER-TUBE BOILERS

Comparison with Cylindrical Type. For many years the cylindrical boiler was almost the only type used in marine work, and

for that reason it attained a high state of perfection. From time to time, engineers tried to introduce water-tube boilers in place of the cylindrical, but on account of poor design, faulty construction, or bad management, the experiments were not entirely successful. At the present time, however, an increase of speed is demanded and, consequently, higher pressures and lighter machinery are necessary. With this increase of pressure comes increase of weight, cost, and damage in case of explosion, if the cylindrical form of boiler is retained. Engineers have foreseen that the cylindrical boiler must give way to the steam generator which is lighter, stronger, and safer.

A water-tube boiler, if well designed and well constructed, seems to fulfill the requirements. Although the cylindrical boiler is serviceable, efficient, and can be made to stand any reasonable pressure, yet the water-tube boiler possesses many advantages over it.

The principal objections to the cylindrical boiler are the great weight, thick plates, difficulty of moving it into and out of vessels, and its small furnace space. This last disadvantage has already been discussed. Also, when the cylindrical boiler is under forced draft, the time allowed for the products of combustion to give up their heat is short.

Among the advantages of this boiler may be mentioned economy and steadiness in supplying dry steam, and in this respect it excels the water-tube boiler. It is also far better suited for salt water than is the water-tube boiler, but this is not a great advantage at the present time.

Classification. Water-tube boilers are built in a great variety of designs. They may be divided into different classes, as straight tube and curved tube; or the drowned tube, that is, those having the upper ends submerged, and those having the upper ends opening into the steam space; or those having a steam drum and those having none.

For convenience let us divide them into two classes, straight and curved tube. In the first class we may place, among others, the Almy, Belleville, Babcock & Wilcox, Heine, Yarrow, D'Allest, and Niclausse. A few of those having curved tubes are the Thornycroft, Normand, Mosher, and Ward. Some of these have been

discussed in the preceding pages. Only a few of these boilers need be described here, the purpose being to show the manner in which ordinary land practice must be modified to conform with the requirements for marine use.

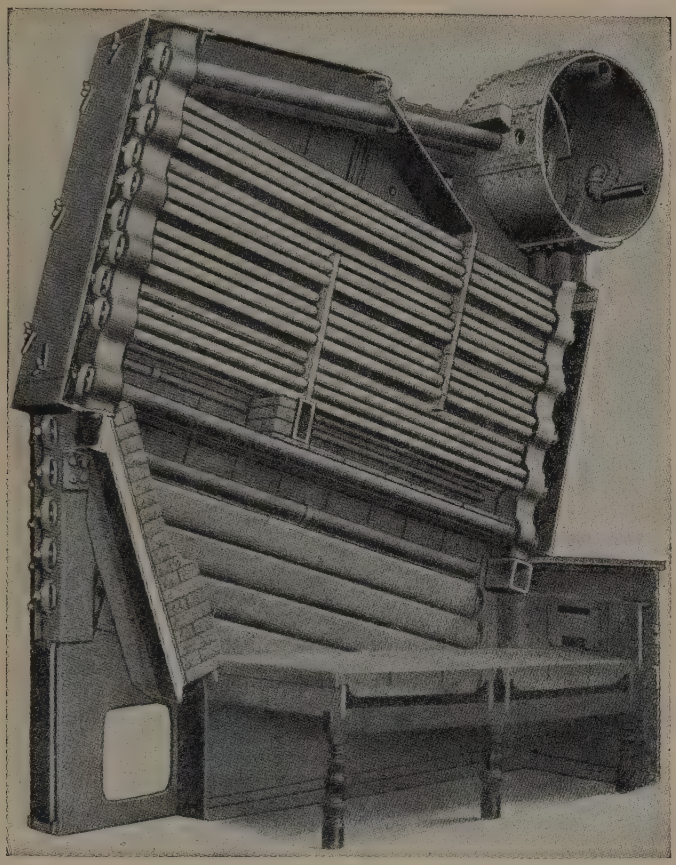


Fig. 73. Sectional Model of Babcock and Wilcox Marine Water-Tube Boiler
Courtesy of The Babcock & Wilcox Company, New York City

Babcock & Wilcox Marine Water-Tube Boiler. In Fig. 73 is shown a sectional view of a model of a marine type of the Babcock & Wilcox boiler, looking from a rear position toward the firing end. All the essential features of this boiler are clearly shown, there being set up for purposes of the illustration two complete sections united with the end of a steam and water drum.

Attention is called particularly to the forged-steel rectangular-shaped boxes, inclined at the same angle as the tubes, lying alongside the grate surface and communicating with vertical forged-steel headers. With the exception of the bottom row of tubes and the circulating tubes above, it is customary to employ small diameter tubes expanded into forged-steel serpentine headers in groups of four. Each handhole communicates with a group of four tubes, the idea being to avoid the use of a multiplicity of handhole caps.

It will be noted that the transverse method of baffling is employed, but that the low end of the boiler is located in front. The bottom row of tubes supports tube tile projecting upward from the inner end of which is the first cross-flame plate encountered by the gases. The gas outlet is at the top front immediately behind the cross-drum. The boiler is enclosed within a steel casing lined with fire brick, and the whole constitutes a very compact economical boiler. To prevent harmful galvanic action and, consequently, internal corrosion, it is customary to install zinc plates with positive metallic contact between these plates and the iron attached to the steam baffle plate within the boiler drum. The plan is to employ an electropositive metal which will receive corrosion attack in preference to the metal of the boiler when galvanic action takes place. Even though such action ceases after a few hours of operation, it is important to employ zinc as a protection against corrosion owing to the presence of air in the feed water.

Standard Water-Tube Boiler, U. S. Wooden Steamships. In order to expedite the building of boilers for the United States emergency fleet, the U. S. Shipping Board Emergency Fleet Corporation, having charge of the building of the ships for the Shipping Board, designed the boiler illustrated by Fig. 74. This is like the Babcock & Wilcox marine previously dealt with in being a straight-tube cross-drum boiler but differs from it in several important particulars. The scheme of design is such as to permit the construction of the boiler in any well equipped shop, making it possible for a relatively large number of boiler manufacturers to engage in production rather than confining the output to the capacities of a few boiler shops only. It was the preservation of this production feature which led to the selection of a "box header"

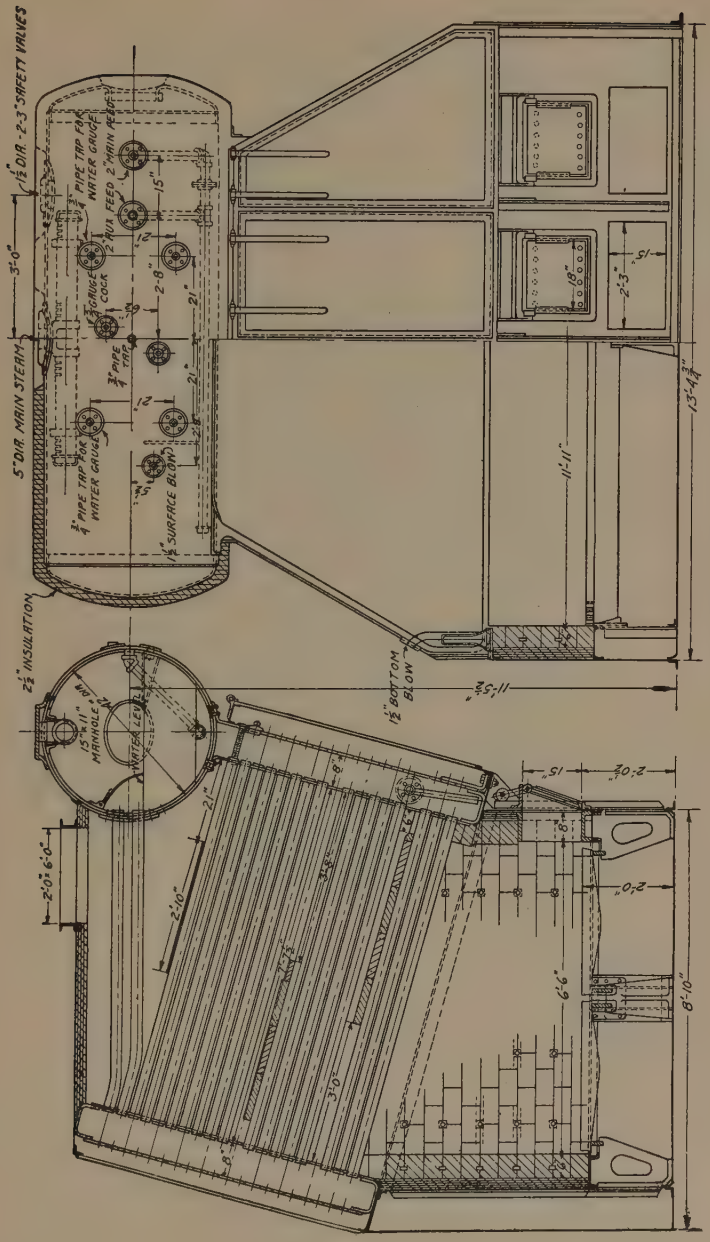


Fig. 74. Longitudinal and Cross Sections of Standard Water-Tube Boiler for Wooden Emergency Fleet

construction instead of the sectional type, which in turn influenced the design by the selection of tube sizes and spacing to fit.

The system of baffling is longitudinal instead of transverse, dead spaces within the tube region being avoided by gaps in the baffle placements where normally they would meet the header tube sheets. To accommodate the baffles, full spaces are created by leaving out horizontal rows of tubes where they would occur in the cross-baffled type. Also, the tube width of the boilers becomes narrower as the top of the header is approached, the general shape of the back header being as shown in the right-hand view, which illustrates a front half elevation of the front header within its enclosing steel casing. Thus there are 38 3-inch tubes in the lowest and only 24 in the highest full rows of tubes.

The standard boiler has a total heating surface of about 2500 square feet and 77.5 square feet of grate surface and is designed to withstand a working pressure of 200 pounds gage when complying with all the rules and regulations of the U. S. Steamboat Inspection Service applying to marine water-tube boilers for ocean and coastwise trade. Among special features it may be mentioned that the cover plates closing the holes opposite each tube are conical steel plugs, held in place by cup-shaped yoke plates and forged-steel nuts screwed upon threaded stems. The joints are made tight by means of copper ferrules, the inner edges of the handholes being rolled with a special expander to allow flaring of the copper ferrules. The plates therefore receive the pressure which tends to close the handhole openings, thus relieving the plate stem of the pressure load.

These boilers are equipped with the customary complement of fittings and trimmings suitable for marine practice and are fully steel encased outside of fire-brick lining.

Almy Water-Tube Boiler. In Fig. 75 is shown a front view of an Almy marine boiler, with its outside casing, grates, and fittings removed. It will be noted that the boiler is made up of straight malleable-iron tubes, connected by special fittings with one another and with manifolds at the bottom and top terminals. The sections that extend along the side from the bottom manifolds to the side top manifolds form a loop extending over above the fire so as to form the roof of the fire box. The sections arising

from the rear bottom manifold form two loops, finally entering at the top front manifold. A flat continuous coil extending over the entire top is a heater section. The front top manifold is connected to a vertical steam dome, or separator, the lower end of which is riveted to a horizontal water reservoir extending across the front of the boiler. The steam connections are made at the top of the separator, while the water reservoir is connected by down flow pipes to the ends of the bottom manifolds in front.

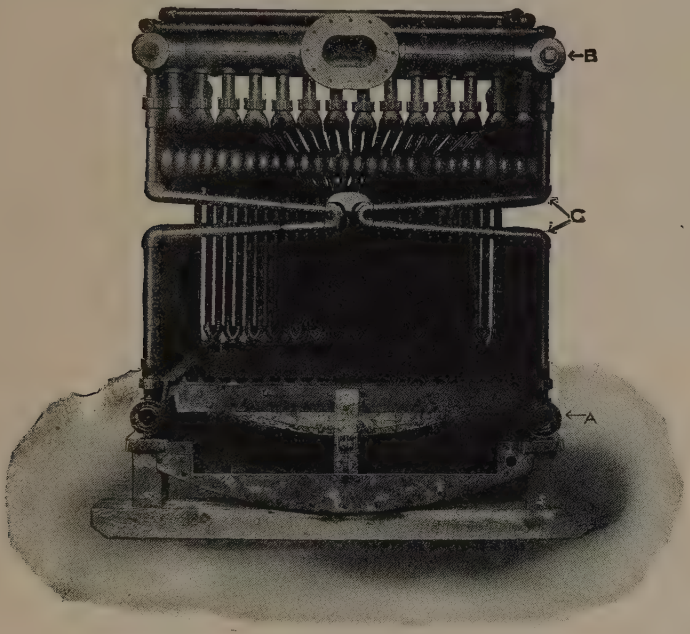


Fig. 75. Almy Sectional Water-Tube Boiler
Courtesy of Almy Water-Tube Boiler Company, Providence, Rhode Island

No baffling is placed inside the heating surface, the expectation being that the heated gases will envelop the tubes throughout. The particular characteristic of the boiler is the very large percentage of the heating surface that is in direct line with the radiant heat coming from the fire.

Double-Tube Type. This boiler is also made in what is known as the double-tube type, the expression in this case meaning that a double row of tubes following the same general contour is employed in place of one tube as shown in the illustration. This expression

"double-tube" must not be confused with that employed elsewhere in this book where one tube is placed inside another.

Variations from Standard Land Types. The variations from standard land types of water-tube boilers are mainly those concerned with length of tubes and the use of cross-drums instead of longitudinal drums. Because the tubes are shorter they may be of smaller diameter as well, and the use of cross-drums is also permissible for the same reason.

Grate Area. The grate area is determined in a similar manner to that used in designing cylindrical boilers; but for most types the area must be greater, so that the heat may be distributed evenly over the surface of the tubes. It is not well to have the heat too intense near any of the tubes. The construction of most water-tube boilers allows some space above the fire for combustion.

Steam Drum. The size of the steam drum depends upon the amount of steam generated by the boiler. In order to make it as small and as light as possible, the boilers are sometimes worked at high pressure, and the pressure maintained constant at the engine by means of a reducing valve.

Water-tube boilers having the upper ends of the tubes opening into the steam space have dash plates and internal steam pipes which separate the water and steam.

Advantages over Cylindrical Type. Water-tube boilers have the following advantages over cylindrical boilers:

(1) Lighter (weight about one-half that of the cylindrical).
(2) First cost less on account of less material used.
(3) Less danger of damage in case of explosion.
(4) Large grate area and large furnace volume for combustion.
(5) Greater rapidity in raising steam.
(6) More easily placed aboard or removed.
(7) Have a larger capacity range.

The last three conditions are of great importance in the navy. As to the relative economy, there is much difference of opinion as the conditions vary considerably. In general, the economy is about equal in both types.

The ease of making repairs depends upon the type of boiler. The sectional type can usually be repaired more readily than others.

Disadvantages. These boilers have several disadvantages, among which may be mentioned the following:

(1) Tendency to prime.
(2) Difficulty of feeding.
(3) Sensitiveness to corrosion and dirt.
(4) Difficulty of repairing tubes.

These defects are reduced to a minimum if the boiler is of good design, well managed, and constructed of the best material.

Launch Boilers. The boilers used in torpedo boats, yachts, and launches should be safe, light, compact, and economical. Also, they should be capable of supplying dry steam at high pressures. Small vertical fire-tube boilers are sometimes used, but the water-tube boiler is better adapted to this work. The water-tube boilers already described are built in small sizes and generally give satisfaction. Perhaps the boilers most used for fast launches, yachts, and small vessels are the Ward and Mosher. These boilers are similar in general principles to most marine water-tube boilers but are made small, light, and compact.

BOILER DESIGN

FEATURES OF INDIVIDUAL BOILERS

As the advantages of employing high pressure and superheated steam became increasingly apparent and the sizes of the steam-using equipments became larger, boiler designers were compelled to exercise greater ingenuity and skill not only in order to create structures that would meet the two requirements just stated but also to overcome other difficulties created out of the means taken to afford larger and higher-pressure boiler units. As steam engineering became better understood, such features as internal circulation, effectiveness of heating surface, accessibility, repair or replacement facilities, sizes and shapes of tubes, etc., demanded closer attention. Without attempting to lay down all of the considerations in these several topics, it is believed well to illustrate and explain by typical examples the purposes aimed at by different designers.

CIRCULATION

Fire-Tube Boilers. The horizontal tubular boiler, illustrated in Figs. 11, 12, 13, and 14, being the most common of our fire-tube

boilers, will serve as an example of the class with many fire tubes, and the considerations entering into its design will apply with equal force to the Scotch marine boiler illustrated in Figs. 21 to 25, inclusive. Where a large number of tubes are distributed through a boiler shell, it is now customary to locate the tubes so as to form wider lanes for the movement of steam and water than would prevail were the tube spacing uniform throughout. It is more important to provide these larger lanes for water travel in the case of internally fired boilers built after the pattern of the Scotch marines than in the case of horizontal tubular boilers. Experience teaches that unless such precautions are taken a definite water circulation is not set up and the tendency is to create dead zones within the water space, particularly in a boiler like the Scotch marine, which does not have hot gases impinging upon the outside shell. Fig. 23 shows plainly how extra spaces are provided between tube rows. While the primary reason for the spacing shown is to permit the construction of the combustion chambers in the rear, it is fortunate for circulation that they exist.

Water-Tube Boilers. *Overcoming Resistance to Water Flow.* The circulation within water-tube boilers constitutes one of the most important problems which they present, modern tendencies not only causing designers to avoid restrictions as much as appears to be necessary but also inducing them to afford positive circulation by inclining the tubes to a greater extent than at first would seem to be required. To illustrate this it is well to point out the precautions taken in two boilers of the horizontal water-tube type, representing the extremes of sectional and box-header construction. In Fig. 44 is shown in vertical section that portion of the B & W boiler which is likely to set up the greatest resistance to water flow. It will be noted that short 4-inch nipples connect the several vertical header sections to the boiler drum proper. In the illustration, twelve tubes of 4-inch diameter deliver the water passing through them through one 4-inch submerged nipple at the front throat; longer 4-inch tubes provide the facilities for keeping the boiler tubes supplied with water coming from the rear end of the drum. Manifestly, the flow of water, supposing it all to be solid, through the nipples must be twelve times as rapid as the average flow through any single tube. Turn now to Figs. 48, 49, and 50.

In these are shown the details of construction of Edge Moor boilers in the particular place known as the throat and previously dealt with in B & W boilers. In this instance no nipples are employed. The depth of the water leg is about 1 foot; then, supposing the Edge Moor boiler is also twelve tubes high, the space available for water movement on the way to the drums is an area of about 78 square inches as against about 12 square inches for the B & W boiler. There is this difference between the two boilers: the B & W boiler is pitched $2\frac{1}{4}$ inches to the linear foot, whereas the Edge Moor boiler tube pitch is 1 inch to the foot; consequently, while the B & W boiler may set up a greater resistance to circulation, it also provides what is believed to be a correspondingly greater force to overcome it.

Prevention of Moisture. Some types of boilers, mainly the vertical or semivertical, provide extraordinarily large circulation facilities and sometimes do so to such an extent that the space into which the tubes discharge may be in a constant condition of very active ebullition. If the water tends to foam, this violent stirring accentuates the trouble and additional means must be provided to afford space and time for the water thrown up into the steam space to settle back to the general level. Baffles are provided to receive water and steam impingement, thereby causing the water to lose its velocity while the steam may pass to an additional drum for further separation. The Stirling boiler, Fig. 62, is a good example of this arrangement.

Auxiliary Circulating Pipes. It is sometimes necessary to provide special circulating pipes leading from one drum to another or from the upper steam drum to a lower water drum, as in Fig. 61. This is done because all the tubes of the boiler are intended to carry water and steam upward to the steam drum, thereby affording no way for the water to reach the lower drum except by setting up a counter-circulation resisting that set up by heat transmission. To facilitate the circulation, therefore, the pipe column shown on the left of the illustration is installed and all downward movement of water may take place through this.

Importance of Good Circulation. *Features of Boilers Affected.* In general, the matter of circulation affects two of the most important features of boilers. If the circulation is inadequate, it is

reflected in the inability of the boiler to absorb heat readily and, fully as important as this, in the material curtailment of the life of the parts subjected to heat. This is due to the fact that steam pockets are created on the water side of the heating surface and, in as much as steam is a poor absorber of heat as compared with water, the plates will not transmit the heat to the steam as rapidly as though solid wetness were presented to the plate; hence the metal may become overheated. If the circulation is such as to permit the alternate but rapid formation of steam pockets followed by solid wetness, fatigue of the metal is set up and crystallization ensues. The deterioration under such circumstances is very rapid.

Retirement of Old Forms. It is this one matter of insufficient circulation that has caused in modern boiler practice the retirement of many of the old forms which formerly were well received. Where a high rate of duty is expected regardless of what the character of water may be, a boiler such as that illustrated in Fig. 68 is out of the question. The same comment can be made with reference to Fig. 70, even supposing the materials would withstand modern high pressure and in other respects be satisfactory.

EFFECTIVENESS OF HEATING SURFACES

Heating Surface Problem Difficult. Manifestly no good purpose is served by providing useless heating surface, yet the problem of using all the heating surface provided is not as simple as it may appear. Out of the accumulated experience of boiler builders, designers, and users has come a fairly good understanding of what are the main items to be considered in employing the heating surface properly so that injury in some other particular may not be encountered. Referring to Fig. 41, it will be noted that the boiler is baffled by the placement of two vertical flame plates located transverse to the tubes. It is recognized in this instance that possibly the upper portion of the top rows of tubes near the front headers may not be well employed as heating surface. The same remark applies to a less extent to the bottom rows of tubes in the second and third gas passes. Were expedients adopted to employ these tubes throughout their length to their fullest extent, then so much resistance to the draft forces would be set up that the furnace end of the installation might suffer. It is

true also that the advantage of having gases leave the boiler setting near the top rear influences the design of setting. In the special setting shown in Fig. 48 the attempt is made to utilize the heating surface more effectively by the employment of four passes instead of three. The design undoubtedly accomplishes this purpose but does so at the expense of creating a materially larger draft loss in the boiler-tube region as compared with a more open system of baffling, which effect, being foreseen, is met by using longer tubes than normally as well as by providing greater chimney or fan draft facilities.

Designers of settings do not all agree as to the means that should be taken to accomplish the same effect. The inclined baffle tile and baffle ledges leaning against or adjacent to the tube banks of the boiler shown in Fig. 63, are manifestly installed to cause the gases to travel closely within the tube regions. The boiler illustrated in Fig. 67, not having such ledge baffles permits the gases to seek the lanes not filled with tubes.

In Fig. 61 is illustrated a design that may become ineffective on account of the failure of parts. In this case the two conical baffle rings placed within the center tube cone may burn out, thereby allowing the gases to pass directly to the chimney without further encountering heating surface.

Where the gases have an opportunity to accept a choice of paths, it is seldom possible to make all the heating surface effective, but it is important to avoid two or more paths which the gases may take through the heating surface on their way to the chimney.

Refer now to Fig. 52. If this boiler is so designed on account of space considerations that it becomes relatively high in number of tubes and narrow, then the vertical distance between the upper and lower baffles is too liberal for the gases generated in the furnace and the tendency is for them to travel across the tube chamber without coming into intimate contact with the tubes throughout their length. Such a boiler is faulty in tube arrangement, yet the design may be amply strong and good in all other particulars.

The effectiveness of heating surface is often destroyed by the creation of pockets within the tube chambers in which large quantities of soot and fine ashes may accumulate without being readily displaced. Such a trouble is accentuated by the fact that,

when a pocket exists, gas circulation within the pocket is of low velocity and the means taken for the blowing out of soot becomes ineffective because the gases, moving slowly, permit the soot to fall back after being stirred up. In other words, there is no special difficulty in removing soot where the gases travel with high velocities, but it is almost impossible to remove it unless there is a swift-moving current to carry it after it has been dislodged.

Absorbtion of Heat by Radiation. The most effective heating surface that can be obtained is that which is in the direct line of radiant heat coming from the fuel bed. It is this peculiarity of the heating surface of the externally fired shell boiler that has retained this type in such general use as to constitute for moderate pressures the most common boiler met with. In this instance the boiler shell is located immediately above the fire and the transmission of heat through the relatively thick shell metal, even when internal circulation is not especially good, is very rapid. Fire-box boilers are a still more striking example of the rapidity of radiant heat absorption. Those boilers of the water-tube type that present large quantities of heating surface to the radiant heat action of fires are invariably more economical steamers than those which are not so liberally provided with heating surface within range of radiant heat. Unfortunately the very causes of a high rate of radiant heat transmission sometimes set up difficulties in other particulars, among which may be mentioned the likelihood of forming steam pockets due to faulty circulation, which in turn may cause tube failures to an excessive degree.

ACCESSIBILITY

Provisions Usual for Inspection and Cleaning. Under this topic the main problems are those of the plant designer rather than of the boiler designer. There are practically no manufacturers of special boiler equipment that do not provide facilities for internal cleaning or inspection of pressure parts. The facilities may be crude or require much effort to employ them, but they are present. It is important in selecting a boiler to look into these matters and, if a choice is permitted, to select the ones wherein the least manual labor is required during operation. An important instance is that of choosing for water-tube boilers the kind of a

handhole cover plate which does not depend too much upon the skill of the operator to make a tight joint when closed. In other words, it is advantageous to select a plate that has the pressure of the steam forcing it against its seat rather than the reverse, not only to reduce the hazard but to reduce the labor and time out of service.

In general, cover plates should be selected that have their pressure loads symmetrically distributed. Odd shaped plates requiring complicated forms of gaskets should be avoided, unless some very decided advantage in some other particular is created by their use.

It is usually less trouble to remove one manhole plate giving access to a whole bank of tubes than to take off as many plates as there are tubes. This is not always an advantage, as the mere taking off of the plate does not complete the job and as in most instances where a manhole plate is taken off in order to make the tubes accessible a man must enter the drum, which imposes the further necessity that the drum be cool and free enough from vapor to permit him to enter to perform his work.

Replacement of Tubes. *Facilities in Boiler Itself.* It is important that any part which may fail, such as a boiler tube, be removed and replaced without disturbing too many other boiler elements. The Stirling boiler is an example of one where tube placing is such that even the most remote or interior tube can be passed out from its nest without getting down other tubes. The practice of so designing boilers is becoming quite general and is to be commended unless carried so far that the gases do not have a fair attack at the heating surface.

Space Facilities. In designing or installing a boiler the only safe assumption is that any one of the tube elements may fail and require replacement. For this reason not only must the boiler permit having its tubes replaced but spaces surrounding the boiler must also be provided. For instance, a straight-tube boiler like the horizontal water-tube types will require a space in one direction, either front or back, equal to the length of the tubes. The same remark applies to any of the fire-tube boilers, such as the horizontal tubular and the Scotch marines. To replace the tubes, the boiler illustrated in Fig. 47 must have a space covering

a rather large horizontal area. Some forms of vertical boilers require almost double the installation height in order to replace tubes without wrecking the boiler setting.

SHAPES AND SIZES OF TUBES

Straight vs. Bent Tubes. It is always desirable to retain tubes in a straight condition as manufactured instead of bending them to some particular shape, since the user need not carry in reserve a number of different shapes and it is also easier to inspect and clean them. It does not follow, however, that a bent-tube boiler is necessarily less to be desired than a straight-tube boiler, for it is more than likely that the bent-tube boiler may be better able to accommodate itself to the space in which it is to be located.

Tube Diameters. *Fire-Tube Boilers.* In the matter of tube diameters there is less freedom of choice than as to shape. If the boiler is of the fire-tube type, then the diameter of the tube plays an important part in the matter of draft reduction. The locomotive boiler is a good instance of the use of tubes of small diameter being made possible by exceedingly high draft created at the exhaust nozzle. If the attempt were made to apply locomotive tube practice to stationary practice it would be found impractical because the tubes would be too small, would rapidly clog up with soot, and even when clean would impose too much of a restriction. In general, the longer the fire tube, the larger its diameter needs to be.

Water-Tube Boilers. In water-tube practice, tubes of small diameters are not suitable in that the application of intense heat tends to create steam pockets within them, because the circulation forces cannot overcome the water flow resistance. Tube failures due to overheating, fatigue, or scale formation may combine to make their cost prohibitive.

It is a fair statement that the greater the rate at which the boiler-heating surface is expected to operate the larger should water tubes be; also, the longer the tubes the larger the diameter. The reverse is partially true with respect to fire tubes, and in this instance the practical limitations are those set up by the available draft.

PLANT FEATURES INFLUENCING BOILER DESIGN

Analysis of Problem. While it is impossible to take note of the many items that must be considered in the problem of designing steam generating plants, it is not out of place to indicate briefly the salient considerations. In presenting a few of the most vital elements of boiler plant design the most intimate association of the several topics or divisions of the subject is presupposed, it being inevitable that the elements of water, fuel, steam demand, etc., are closely interrelated so far as influencing the type and size of boiler units is concerned.

As a fundamental truth it may be stated that all types of boilers that have withstood the test of time service can, in general, be made to give practically the same economy of service, provided the features external to them are selected with good judgment. By external features are meant tight settings, good boiler water, adequate draft, etc.

Personal Element. The reader must, however, bear in mind that whatever the intention of the designing engineer the performance of the equipment depends upon the one person or group of persons who operate it. In other words, a prime requisite is that the equipment shall be of such a character that the labor service available is able to grasp the possibilities offered by the plant; therefore, if the plant steam output demand is not large enough to warrant the engagement of highly skilled operating engineering, then, of course, it shows decidedly poor judgment to select equipment of a nature effective only with expert manipulation.

Size of Plant. Where the steam demand requires the installation of more than one unit, the problem is sometimes quite difficult. In general, it is usually not good practice to select two units instead of three of the same aggregate rating. On the other hand, it is not as economical, either as to first cost or later operation, to select many small units in place of a relatively few large ones. Where a choice is permitted, the plant designer should aim to provide an additional stand-by unit or the space in which one may be placed. In the latter event, provision should be made to permit the addition of the breeching and other boiler room facilities without disturbing the character of the original installation.

Stokers. The size of the boiler units as well as their number determine the feasibility of installing stokers. The latter are not usually serviceable or economical when combined with boilers of less than 150 horsepower. Some types of stokers do not become economically worth while until the sizes both of the units and of the plant as a whole become quite large, the character of labor required for operation and their cost being against the use of the most refined stokers unless the plant has a large output. The nature of the available fuel determines the type of stoker that can be used economically and by learning the economical size of the stoker of that type in common practice the plant designer may come to fix upon boiler sizes somewhat different than he would select if not considering stokers. If stokers are justified by other considerations, the boiler design must be made to fit, by which is meant that the dimensions of boilers of any given make may vary to suit furnace size and shape. Also, the boiler baffling may require modification to get satisfactory results.

Water. One of the troublesome elements in many cases is the character of water that is available for plant use. If the water precipitates a very hard scale, then it is usually best to treat it before admitting it to the boiler, but even with such precautions there are occasions when some scale will appear. If the scale so formed cannot be completely eliminated by treatment, the engineer is likely to be justified in ruling against the adoption of water-tube boilers, though, no matter what the type of boiler, scale of this character is likely to cause trouble. Or, he may be justified in rejecting a water-tube boiler in which the labor of making the tubes accessible for cleaning is much greater than in a boiler of another type; for instance, he may choose a vertical or semi-vertical water-tube boiler in place of a horizontal water-tube boiler having a multiplicity of handhole plates. It is to be said, however, that unless the water contains common salt in solution there is hardly any reason why water treatment will not permit the greatest freedom in the selection of the type of boiler. Where the available water is unsatisfactory, a water-treating equipment of good design is always a paying investment, no matter what type of boiler is selected.

Fuel. Aside from grate sizes and character, it is extremely important that the nature of the available fuel be considered in

connection with the type of boiler selected. In the most favorable furnaces, soot or fine ash is bound to develop at the grate and pass to the heating surface where large portions may deposit. Since dirty heating surface on the fire side is more costly in fuel than any other form of boiler uncleanliness, if the fuel itself contains a relatively large percentage of volatile or soot-making matter, then the engineer should select a type of boiler in which the places of soot lodgment are easily accessible. For instance, a three-crosspass horizontal water-tube boiler affords less opportunity for soot deposit in the tube chambers than a horizontal boiler with horizontal passes. In any event, soot removing demands close study in all stages of the boiler plant design, consideration being given to the furnace, the boiler passages, and the spaces around the boiler settings, keeping in mind that the nature of the coal has a direct bearing on the amount of such deposits. Thus the kind of fuel determines to a large extent the kind of stoking or firing equipment which, in turn, fixes the size and shape of the boiler.

Available Space. Aside from the very obvious necessity of choosing boiler units that may be installed within the space assigned to them, there are less obvious factors that need consideration. The fact that an installation may be made does not argue that it is necessarily good, as is attested by the thousands of instances where sacrifices to space considerations were made in the first instance for unimportant reasons. If it is remembered that a boiler is only an absorber of heat and that there is also the problem of heat generation, little difficulty is encountered in understanding the reasons for the following points:

(1) Under no circumstances compromise with the question of providing combustion time and space. If the head room is cramped, make it up by selecting a type of boiler that gives at least ample horizontal room. A reverse situation demands opposite treatment.

(2) Sufficient draft combined with furnace design determines the rate at which the fuel may be burned as well as the economy of heat evolution. A boiler design that does not lend itself to the chosen space without sound breeching design should be rejected. Linked up with this is the whole subject of boiler baffling. When designing a new plant create (by overprovision, if possible), all the draft intensity that may be desired. If looking

for trouble in an existing plant, it will probably be found by an analysis of the draft facilities. The sizes of gas passages and their relative positions and shapes are among the important items.

(3) Do not overlook tube replacement facilities.

(4) Soot removal, whether done manually or by permanent blowers, demands adequate alley ways around boiler settings. Many forms of stokers require side inspection and manipulating space. No other condition is so disagreeable as cramped quarters for routine boiler and furnace operation. In order to get adequate space it may be necessary to reduce setting widths and increase boiler heights when choosing them, but it is usually worth while to do so unless some other important feature is adversely affected.

(5) It is a mistake to install more than two boilers in a single setting, and, where done by choice, the reasons for so doing should be of the best and it should be fully appreciated that sacrifices will be made during the life of the plant.

(6) Many boilers properly designed as to pressure parts fail to be fully effective because of faulty supports, poor baffles, improper expansion provisions, etc., all of which are reflected in the creation of cracks in settings attended by uneconomical heat absorbtion, reduced capacity, and high furnace maintenance costs. This part of the subject warrants the closest study in even the most minute details.

NORMAN E. BURKHARDT
RT. 3 - BOX 89
FRAZEYSBURG, OHIO 43822

EXAMINATION PAPER

TYPES OF BOILERS

Read Carefully: Place your name, student number, and full address at the head of the paper. Any lightweight paper may be used. Do not crowd your work, but arrange it neatly and make it legible. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure you understand the subject.*

1. Why are water-tube boilers lighter than those of the fire-tube type?

2. In the fire-tube boiler are the tubes large or small for forced draft? Why?

3. Describe briefly the Stirling boiler.

4. Classify, under the headings "sectional" and "non-sectional," all the water-tube boilers described in this Instruction Paper.

5. What is the peculiarity of Beggs' Directurn boiler?

6. What are the advantages of the double-ended return-tubular boiler?

7. What is a breeches-flued boiler?

8. Explain the difference between the gas travel of Babcock and Wilcox and the Heine boilers.

9. How does the Belpaire fire box differ from the Wootten?

10. Why are some vertical fire-tube boilers not economical?

11. Describe the fire-box construction in the Manning boiler?

12. Sketch longitudinal section of the Mosher boiler.

13. What boilers belong to the class that may be briefly described as a straight vertical water-tube, single-tube, non-sectional?

14. Describe the Brady boiler. Why is the furnace flue corrugated?

15. Name the boilers which have the following characteristics: *water-tube — non-sectional — straight-tube — water-tubes horizontal or nearly so—steam drum horizontal.*

16. Why should one of the brackets supporting a multitubular boiler be placed on rollers?

17. What constitutes the heating surface of a cylindrical marine boiler?

18. State reasons why water-tube boilers are better than cylindrical boilers for marine work.

19. Where should the feed water be introduced into a cylindrical marine boiler?

20. What is the purpose of the soot blower? How does it effect the efficiency of a boiler?

After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.

(Signed)

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